Multitemporal Landsat for Applied Forest Science

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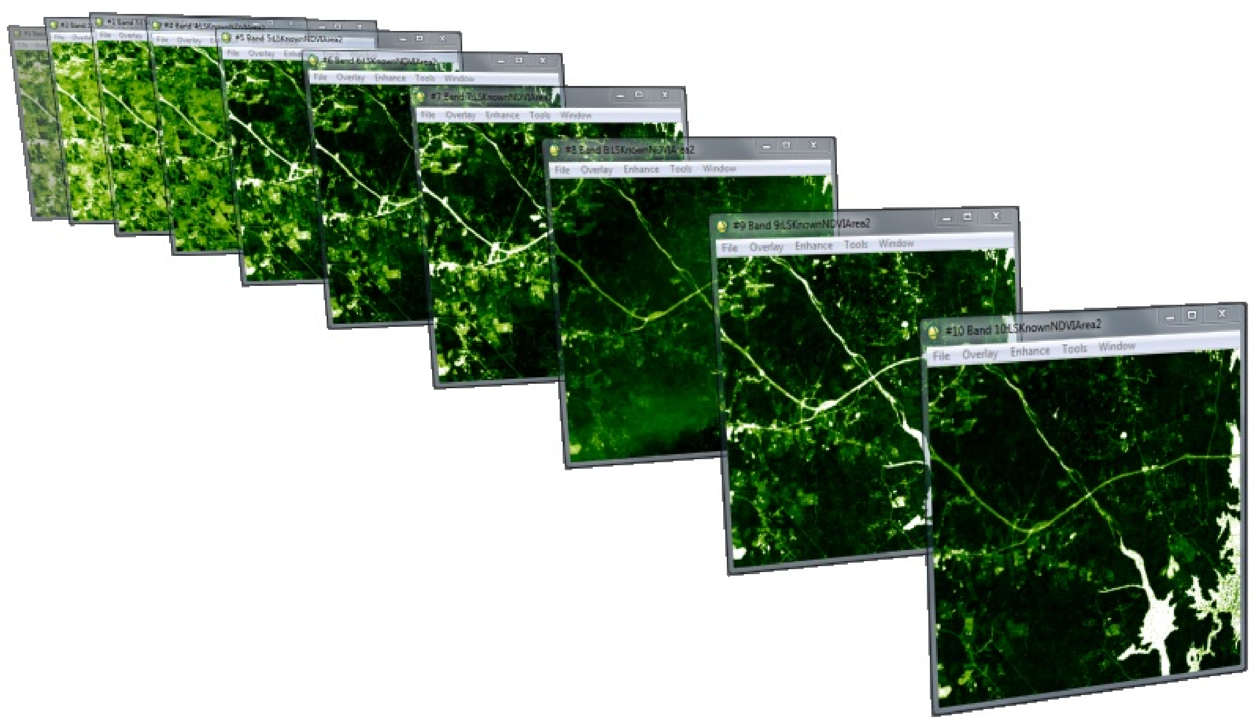
Background

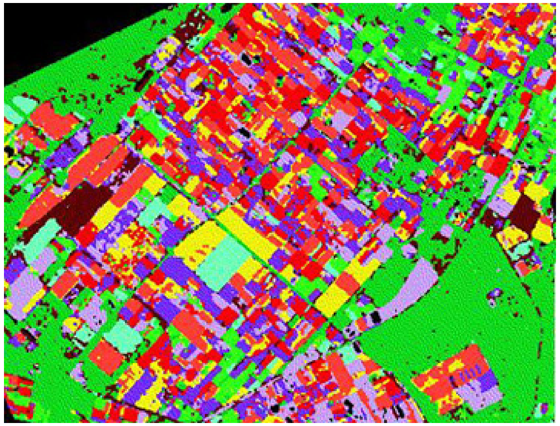
- No-cost Landsat data since 1972 offers an enticing medium for basic and applied ecosystem science
  - 30m pixels allow for sufficient detail in many applications
  - Largely unbroken temporal coverage



Background

- Multitemporal analysis applications

Classification



Source: NASA

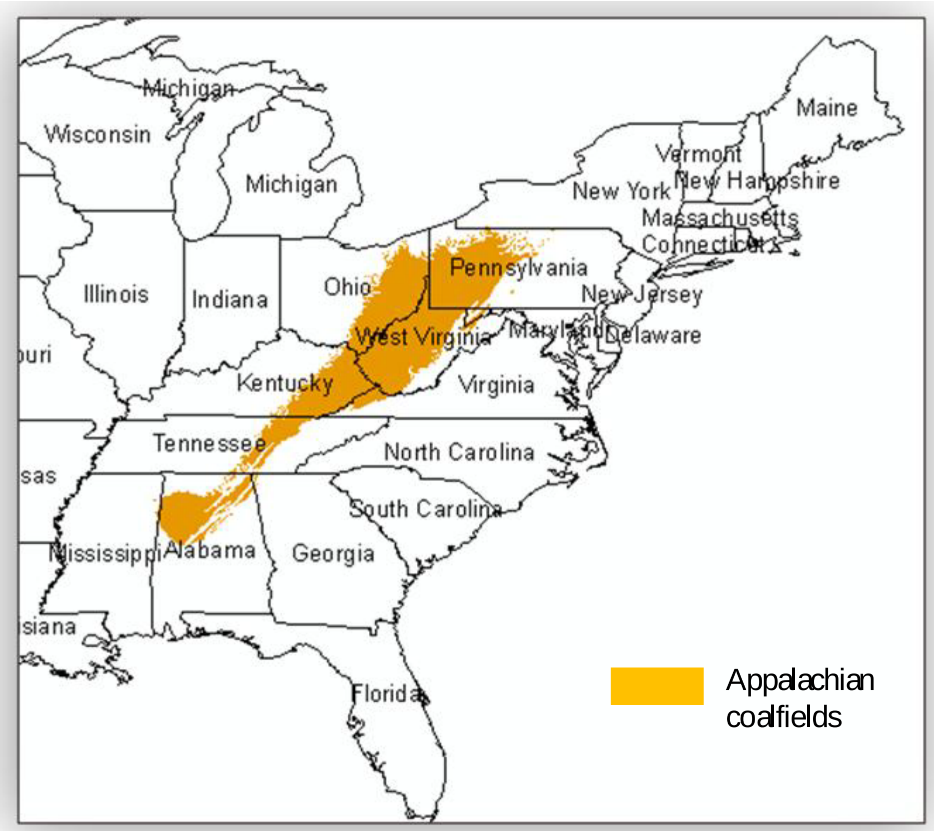
Change/Disturbance Detection

Source: Thompson Rivers University

Phenology

Source: US National Park Service

Appalachian Coalfields



- > 600,000 hectares of lands mined and reclaimed under Surface Mining Control and Reclamation Act (SMCRA), 1977.

- Variety of reclaimed landcover from varying reclamation practices.

- Unavailability of information on:

a. Extent of reclaimed mines
b. Mining (date of mining) and reclamation(when, how, vegetation choice) status
c. Current vegetation cover
d. Forest vegetation recovery potential

Mine Reclamation

"Grassland" reclamation

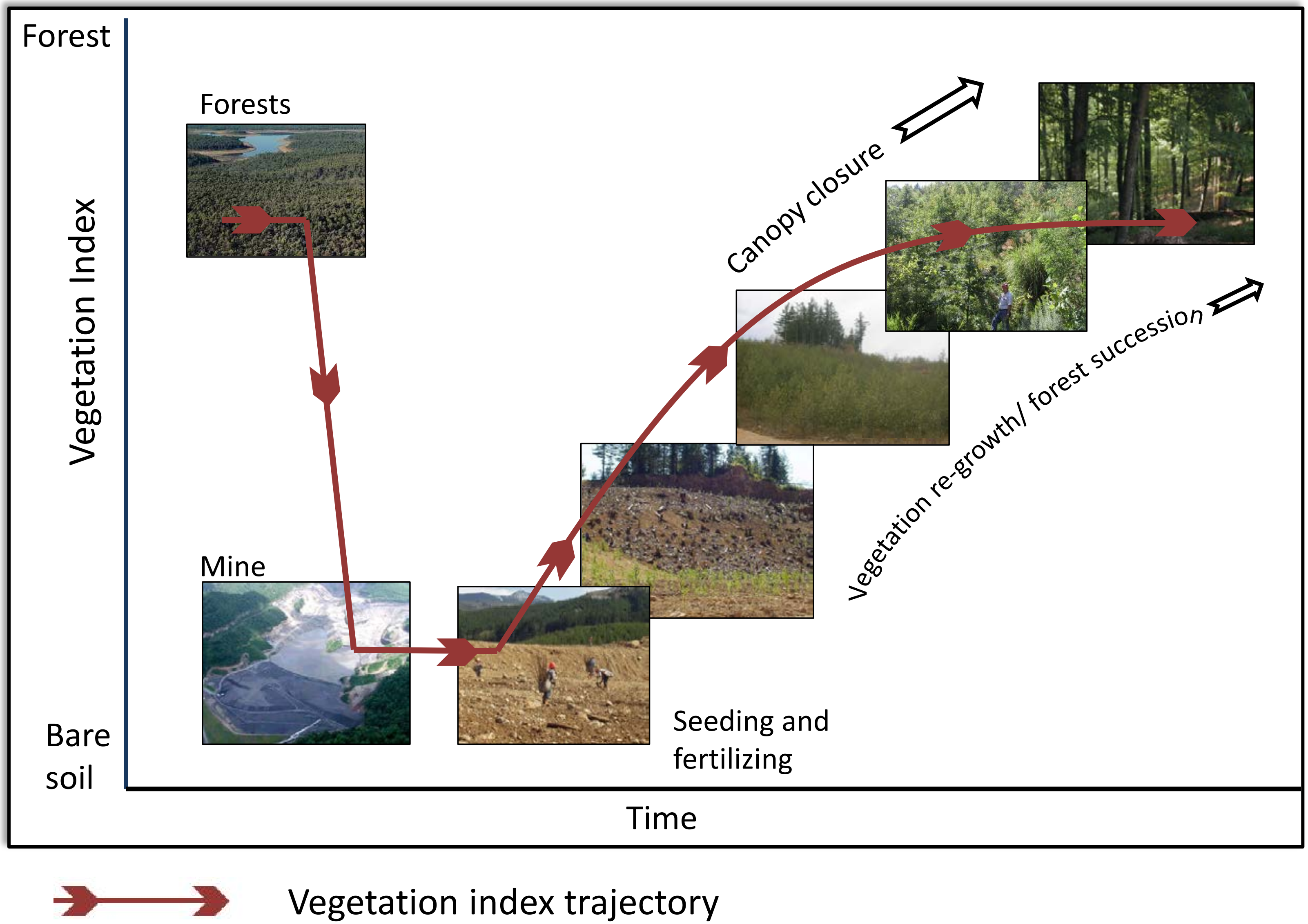
Reclaimed mine landcover

Vegetation is predominantly invasive

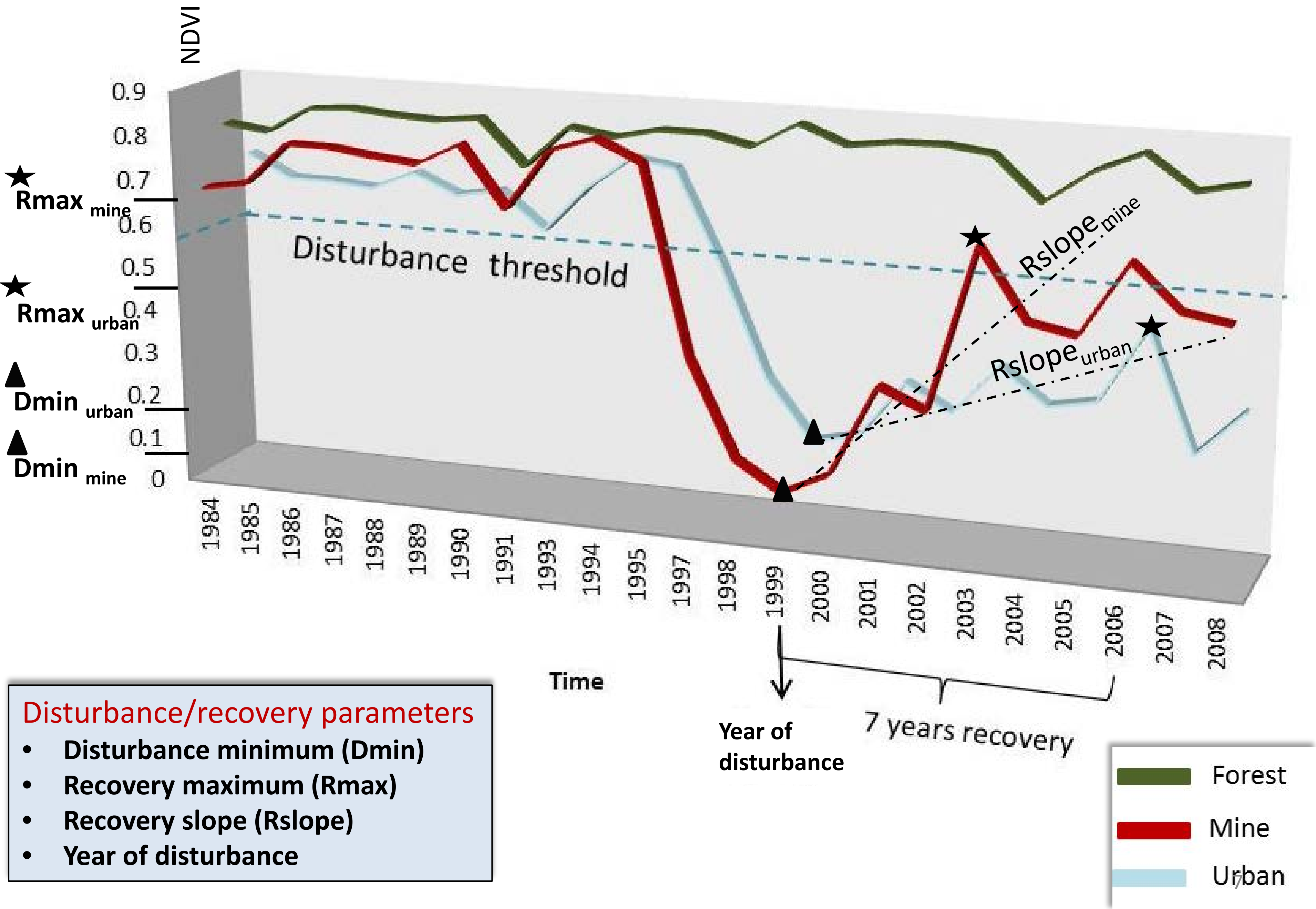
Succession with both natives and invasive species

Reclaimed with trees in the 1980s.

Trajectory-based methods to characterize the temporal dynamics of vegetation (distrubance and regrowth)



Reclaimed mine trajectory and diagnostic parameters



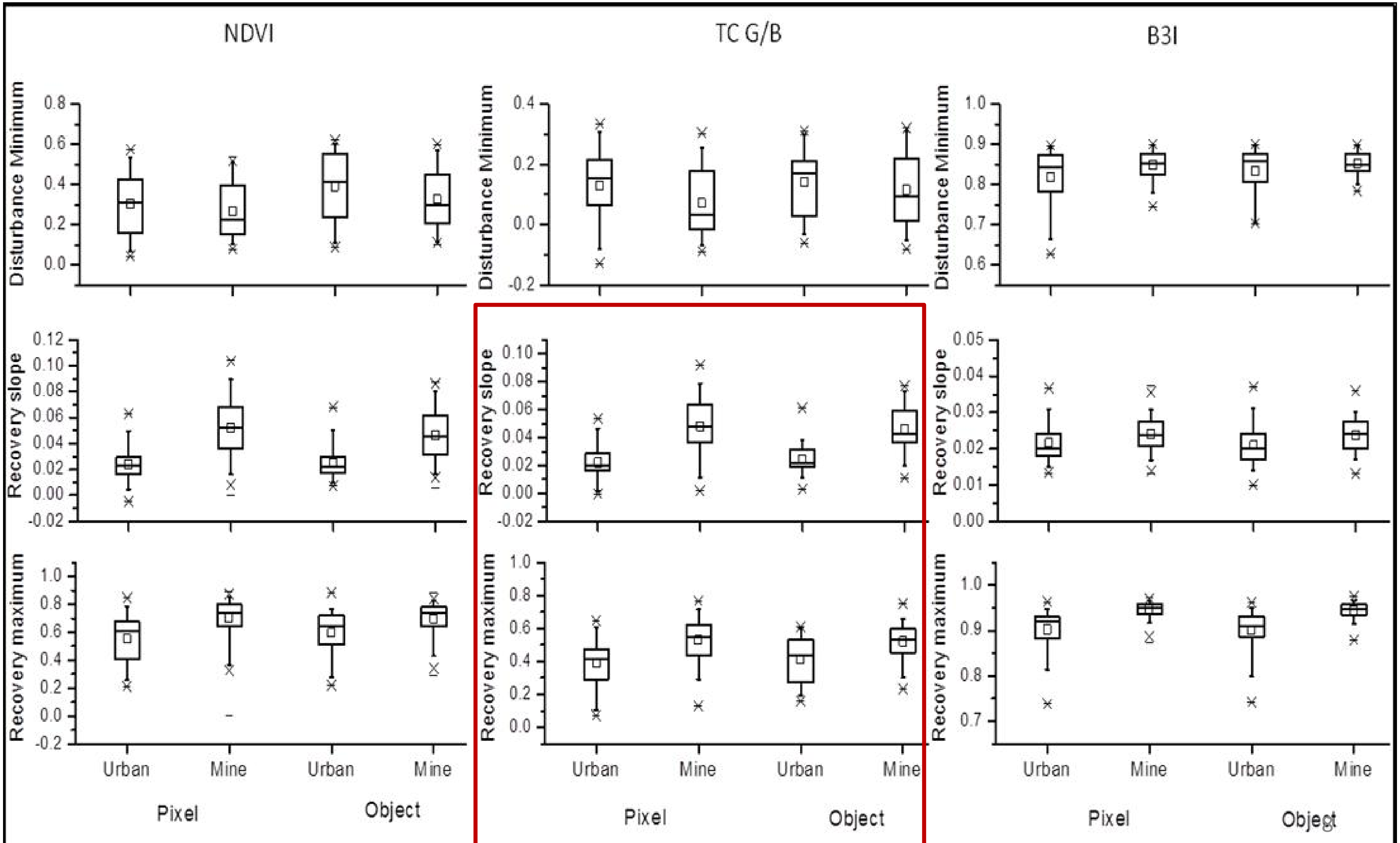
Disturbance/recovery parameters

- Disturbance minimum (Dmin)
- Recovery maximum (Rmax)
- Recovery slope (Rslope)
- Year of disturbance

Results

Trajectory parameters are unique to mining disturbance

- Dmin mines < Dmin urban
- Rslope mine >Rslope urban
- Rmax mine> Rmax urban



Classification accuracy

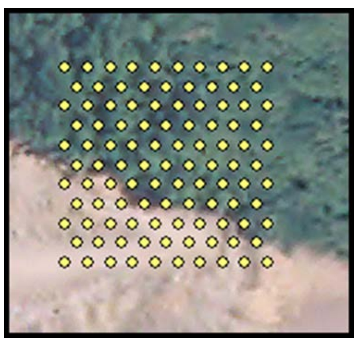
	VI	Correctly classified mines	Correctly classified non-mines	Total validation points	Accuracy
Pixel	NDVI	147	387	612	87.3%
	TC G/B	133	395	612	86.3%
	B3I	126	349	612	77.6%
Object	NDVI	155	383	612	87.9%
	TC G/B	160	385	612	89.1%
	B3I	122	370	612	80.4%

Methodology

Estimation of canopy cover on reclaimed mined areas

- In cooperation with the USDA Forest Service (USFS)
- Model development based on protocol developed for next National Land Cover Database (NLCD) 2011, canopy cover estimation process

Response variable
(woody canopy density, developed by photo interpretation)



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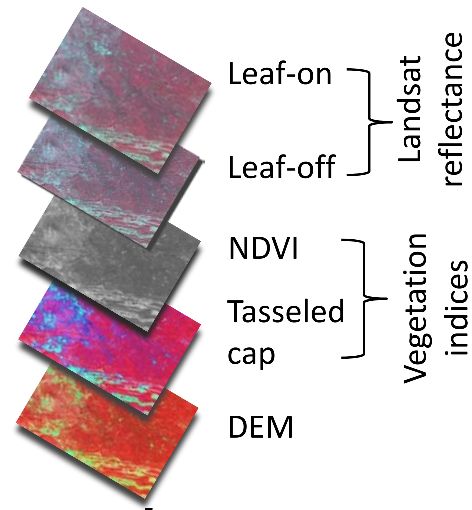
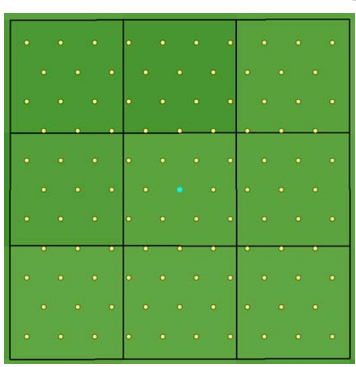
Explanatory variables



Model for:
Mines, Non-mines, Mixed and Combined

⬇

Compare performance of these models



Results

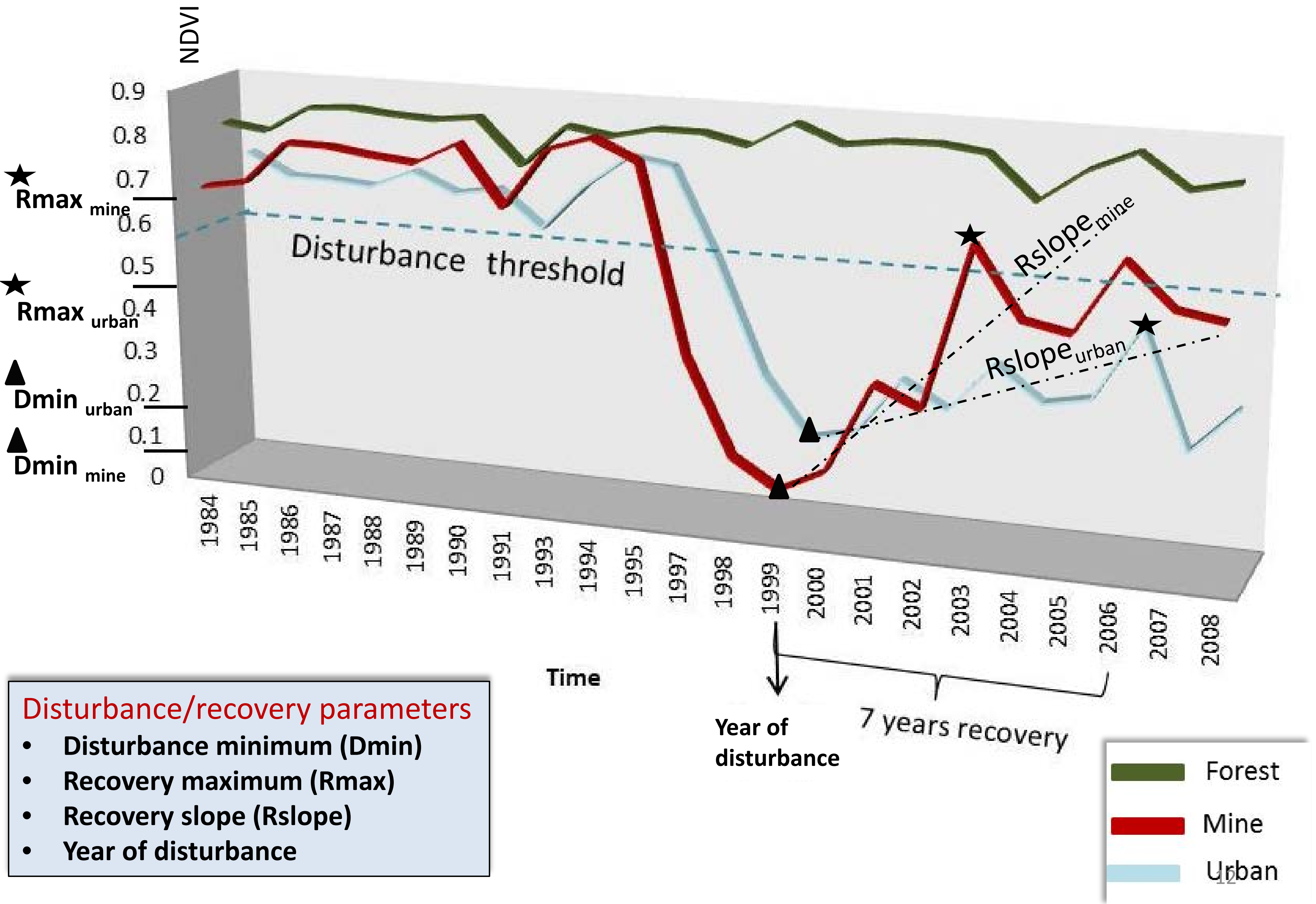
Woody canopy cover prediction model

Groups	R^2	Adj. R^2	RMSE	Pred.R^2
Mines	0.78	0.77	0.16	71.24
Non-mines	0.69	0.69	0.15	67.23
Mixed	0.53	0.51	0.16	48.48
Combined	0.68	0.68	0.16	66.23

Best subsets of variables for the models

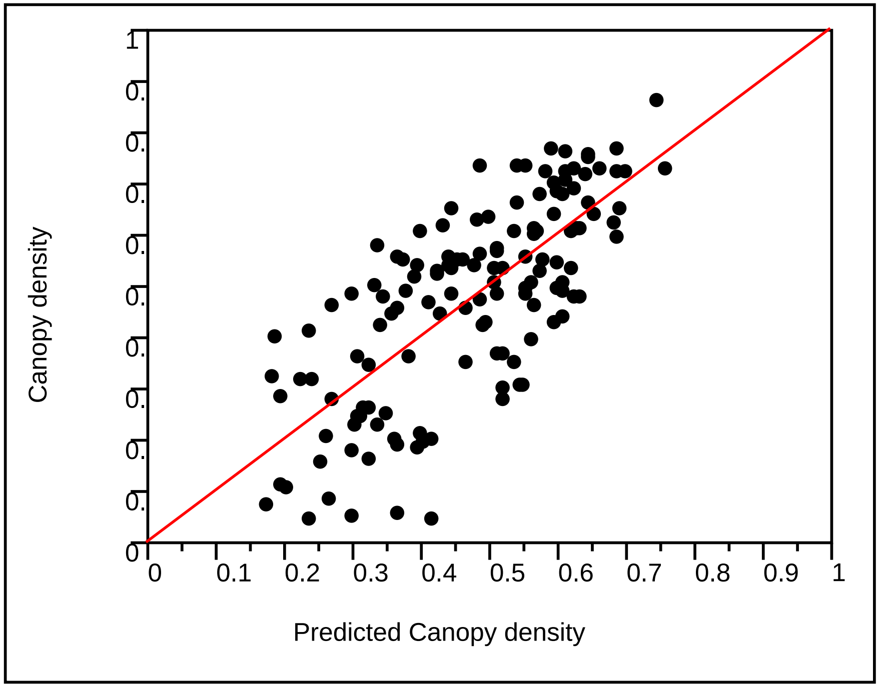
	Mines	Non-mines	Mixed	Combined
Leaf-on B1 stdev				X
Leaf-off B5 mean				X
Leaf-on B4 stdev		X		
Leaf-off B4 mean	X			
Leaf-off B1 stdev	X			
Leaf-on TC1 mean	X			
Leaf-on TC2 mean		X		X
Leaf-on TC3 mean		X	X	
Leaf-on TC3 stdev		X		
Leaf-off TC2 mean		X	X	X
Leaf-off TC3 mean		X		X
Leaf-on NDVI mean	X	X		X
Leaf-on NDVI stdev	X			X
Leaf-off NDVI mean	X	X	X	X
Aspect stdev			X	
Cos aspect mean	X	X		X
Sin aspect mean	X	X	X	X
Slope mean	X			

Reclaimed mine trajectory and diagnostic parameters



Disturbance/recovery parameters

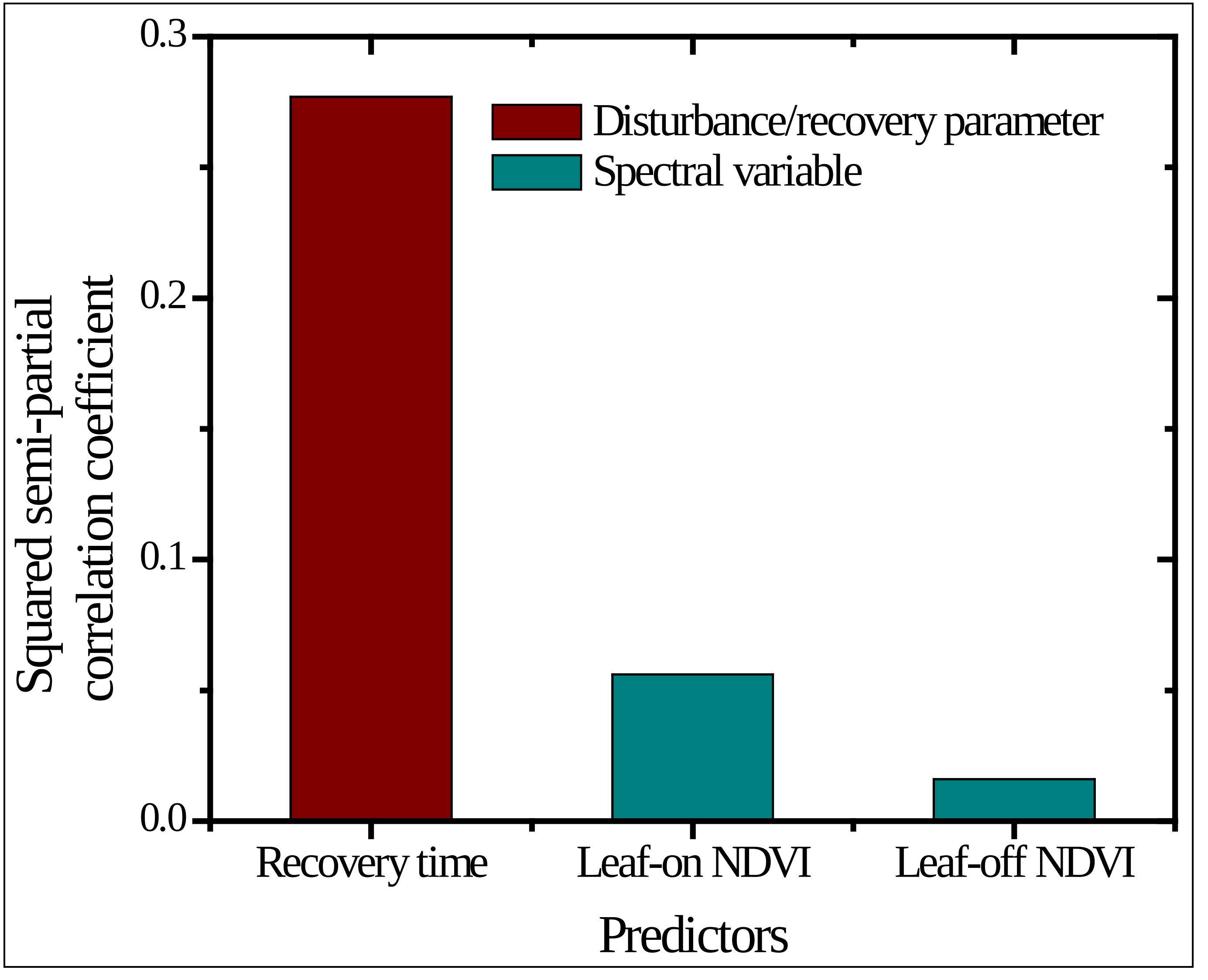
- **Disturbance minimum (Dmin)**
- **Recovery maximum (Rmax)**
- **Recovery slope (Rslope)**
- **Year of disturbance**

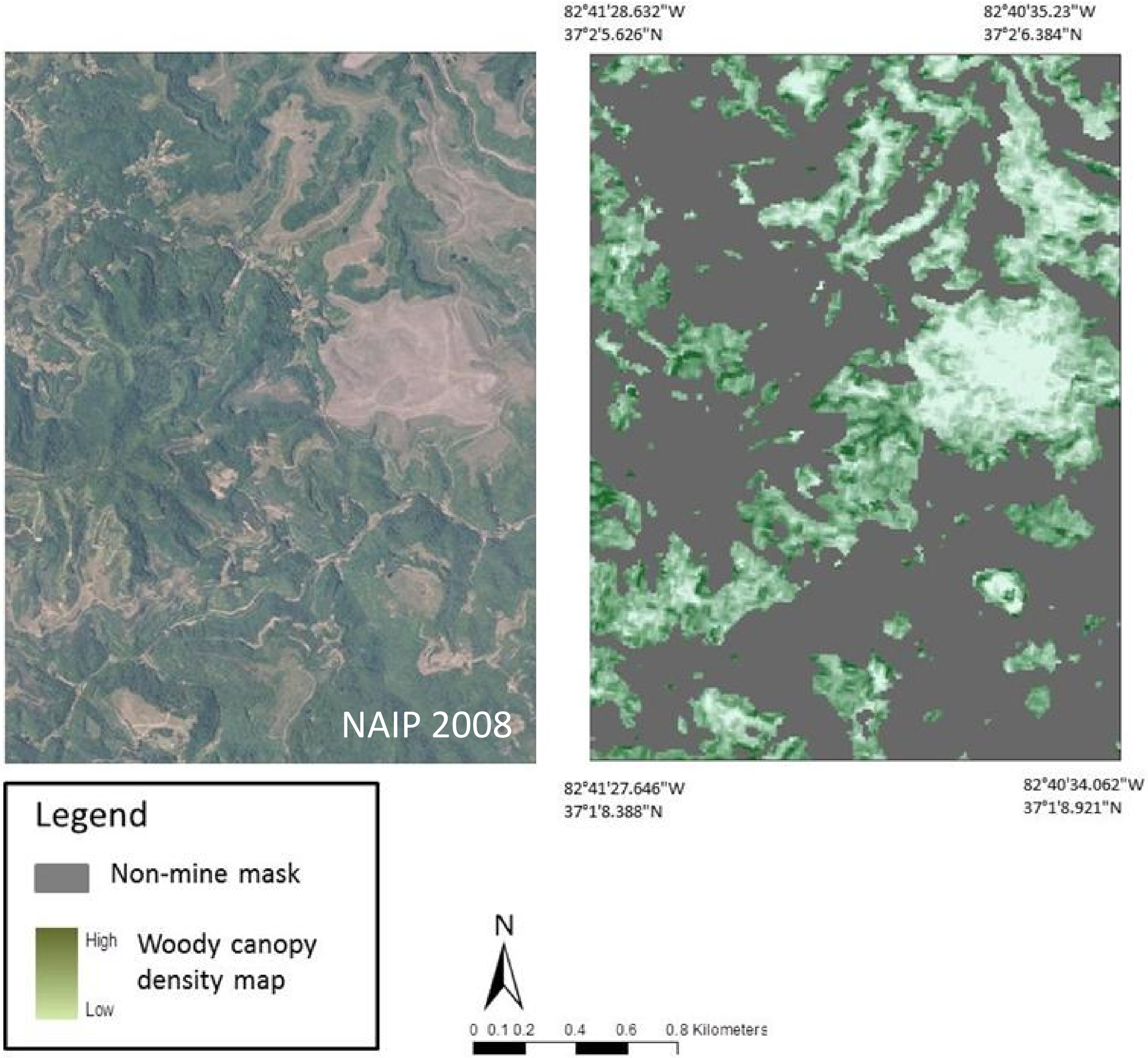


Model 2 summary of fit	
RMSE	0.13
Pred. R^2	0.512

Predictor	Coefficient	Std. Error	P	VIF
Intercept	-0.854	0.211	0.000	
Recovery time	2.366	0.262	0.000	1.127
Leaf-off NDVI	0.211	0.095	0.029	1.155
Leaf-on NDVI	1.149	0.281	0.000	1.159

Unique contribution of each variable in the woody canopy estimation model 2





NAIP 2008
82°41'28.632"W
37°2'5.626"N
82°40'35.23"W
37°2'6.384"N
82°41'27.646"W
37°1'8.388"N
82°40'34.062"W
37°1'8.921"N
Legend
Non-mine mask
High
Low
Woody canopy density map
N
0 0.1 0.2 0.4 0.6 0.8 Kilometers

Crop Residues

- Timing of tillage implementations and/or planting varies;
- NDTI can be affected by vegetation.

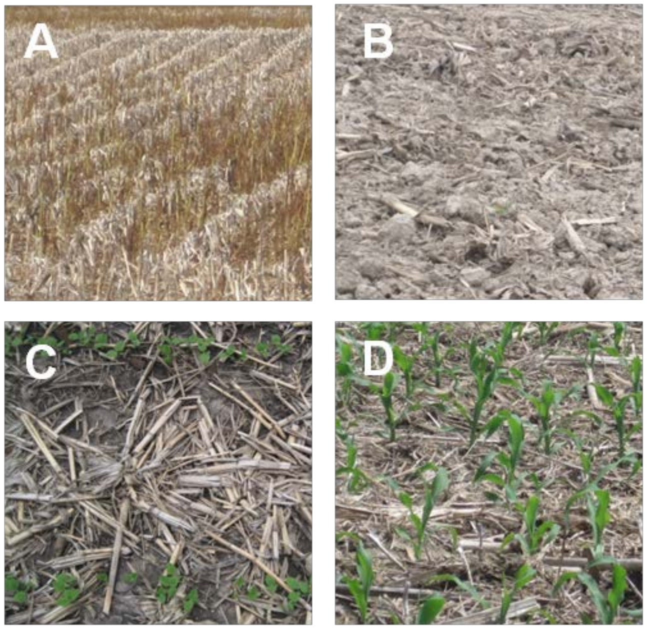


Figure 1. Pictures of agricultural fields: Before tillage (A), after tillage/planting with no or little vegetation (B&C), and crop emergence (D).

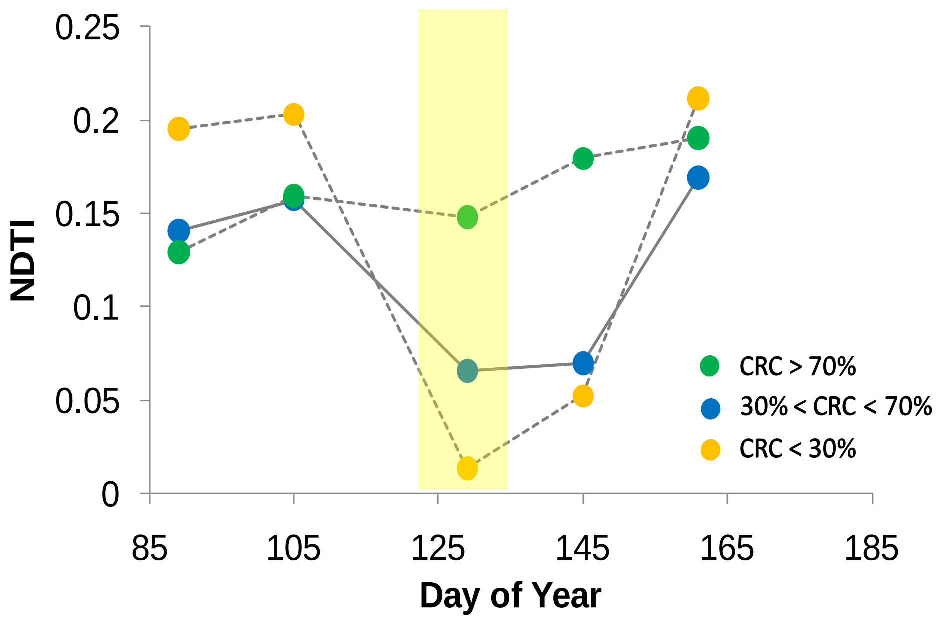
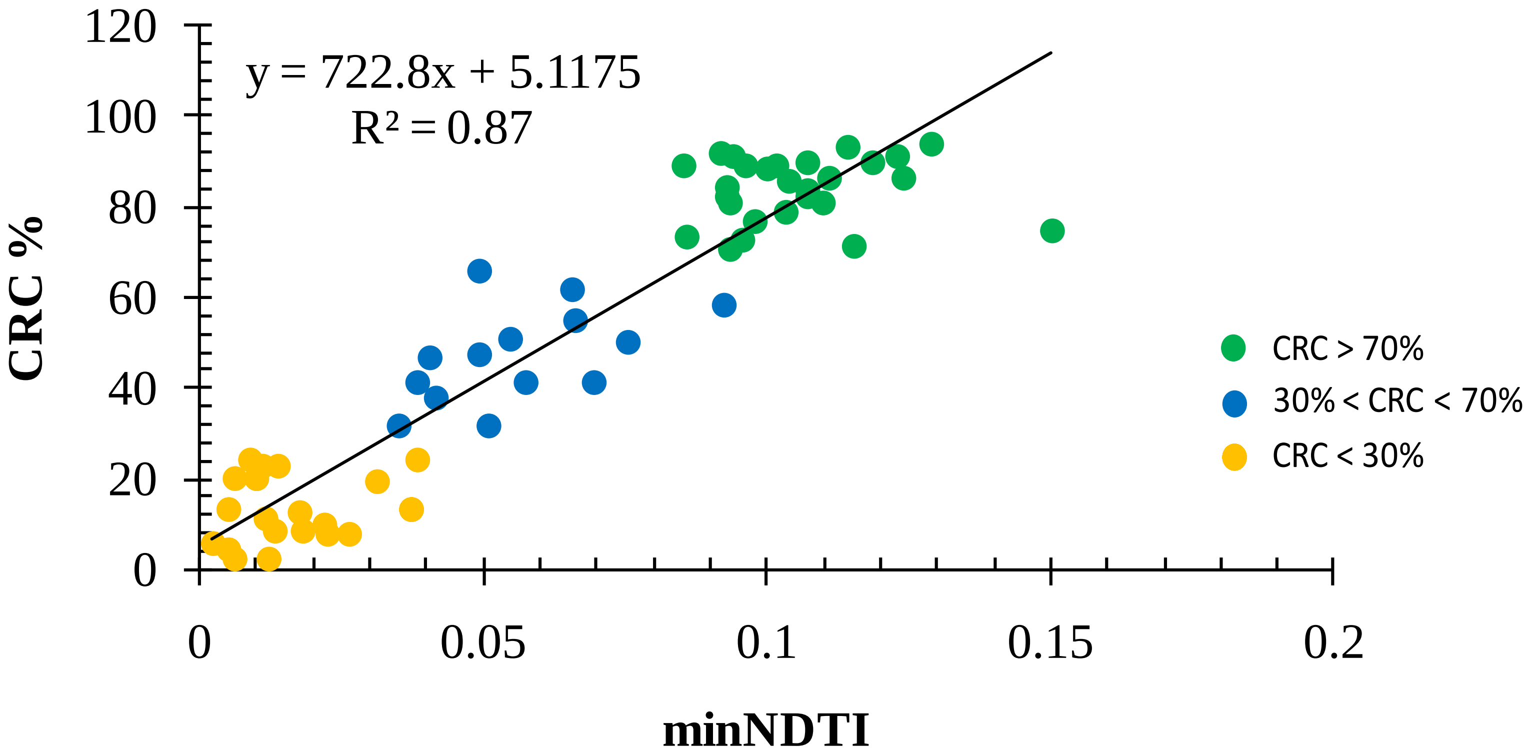


Figure 2. Comparison of time-series NDTI values with different levels of CRC

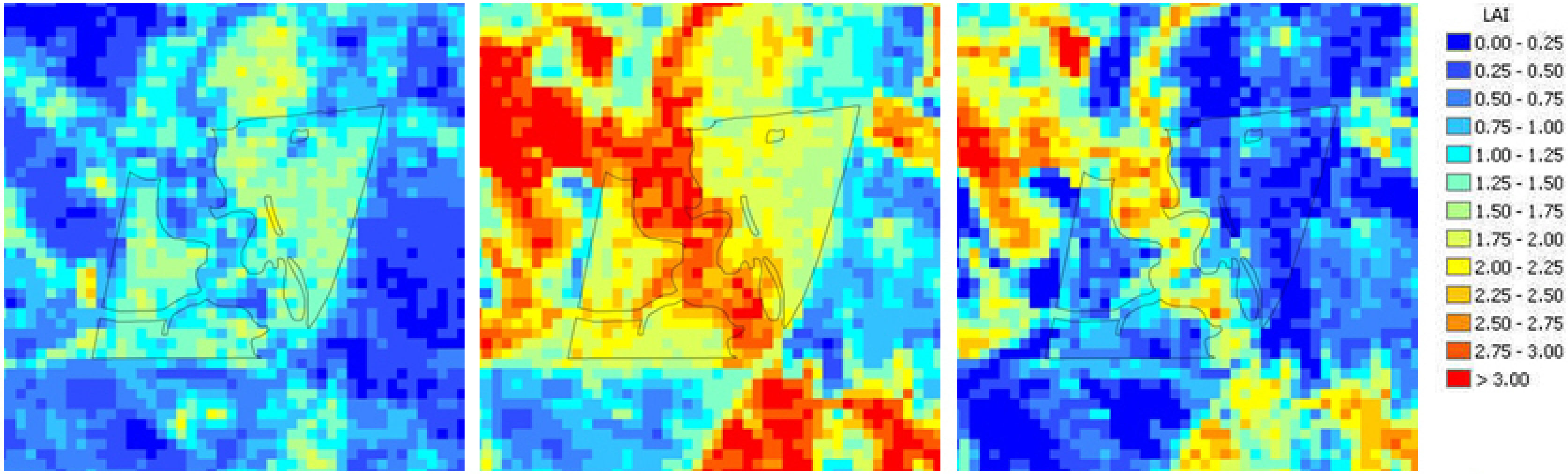
Solution: extract minimum NDTI (minNDTI)

Results

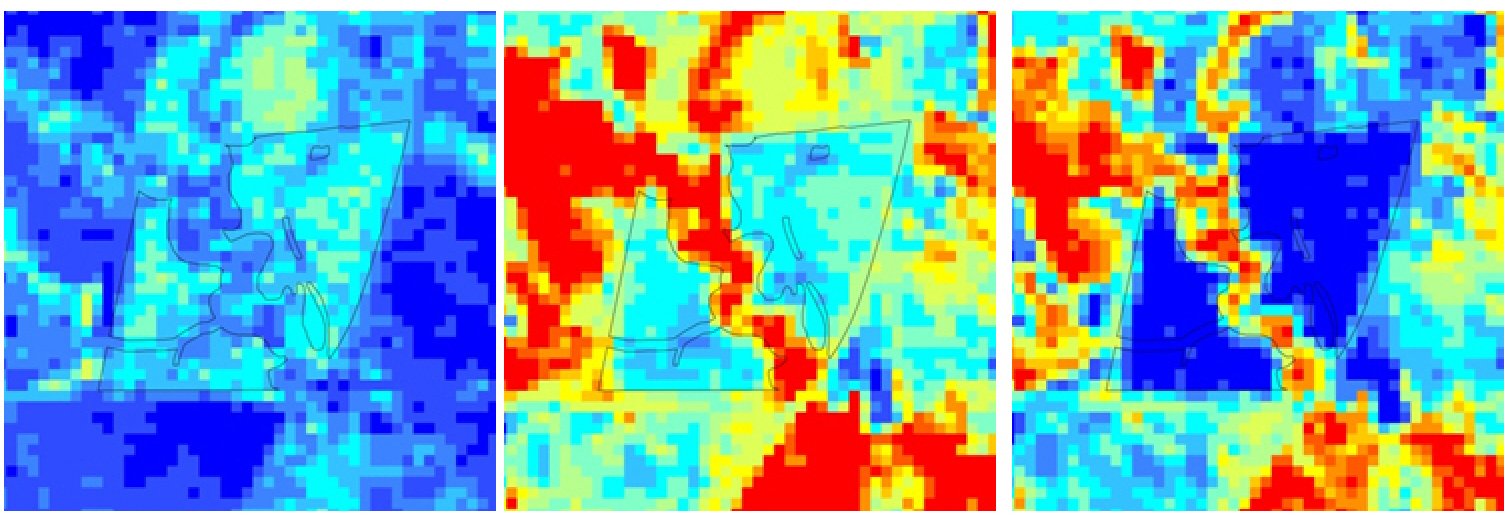


Zheng et al. in review.. Remote sensing of crop residue cover using multi-temporal Landsat imagery, *Remote Sensing of Environment*.

Competing Vegetation Estimates Before and After Release

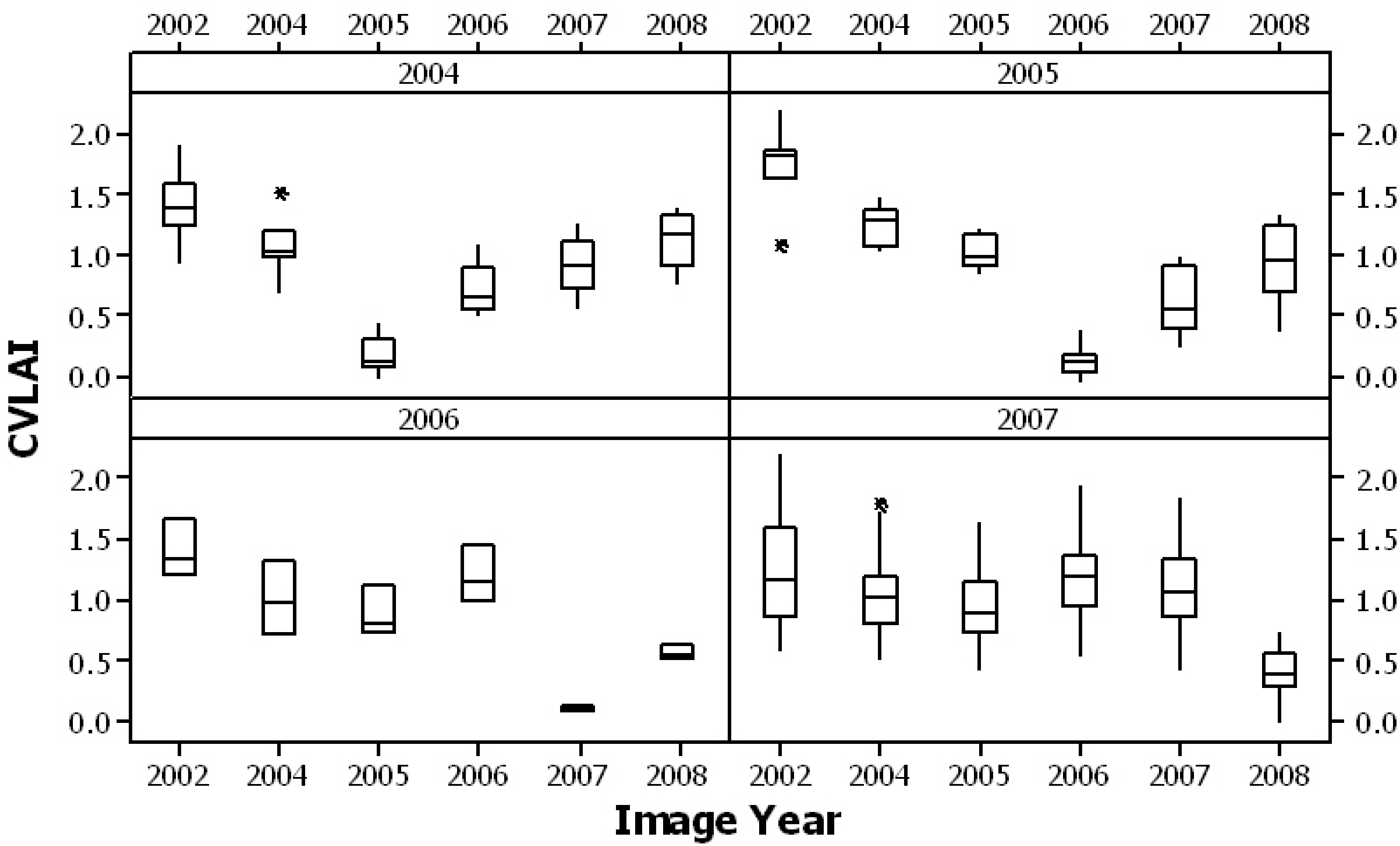


(c) LAI January 9, 2007 (d) LAI May 17, 2007 (e) CVLAI 2007 (May 17 – January 9)



(f) LAI January 28, 2008 (g) LAI May 19, 2008 (h) CVLAI 2008 (May 19 – January 28)

Competing Vegetation Estimates



Panel variable: Release Year

Competing Vegetation Estimates Before and After Release

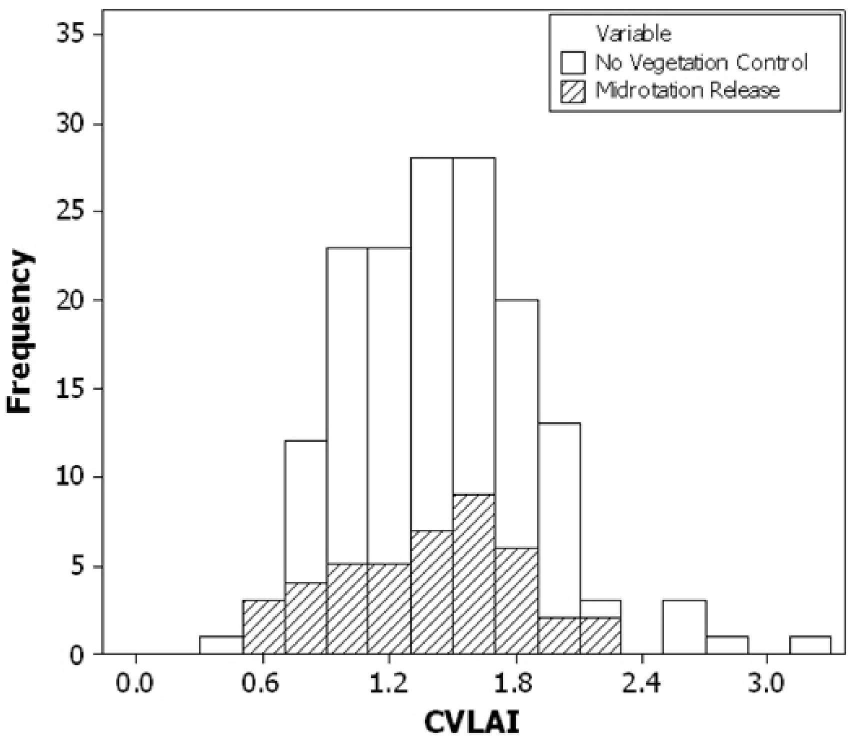


Image year 2002
before any stands were released

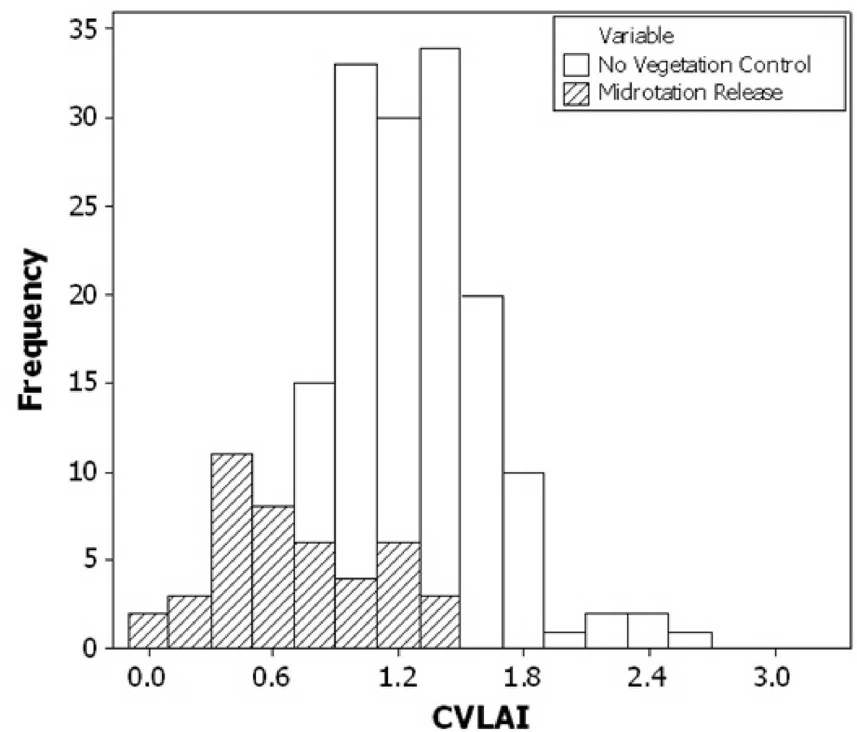
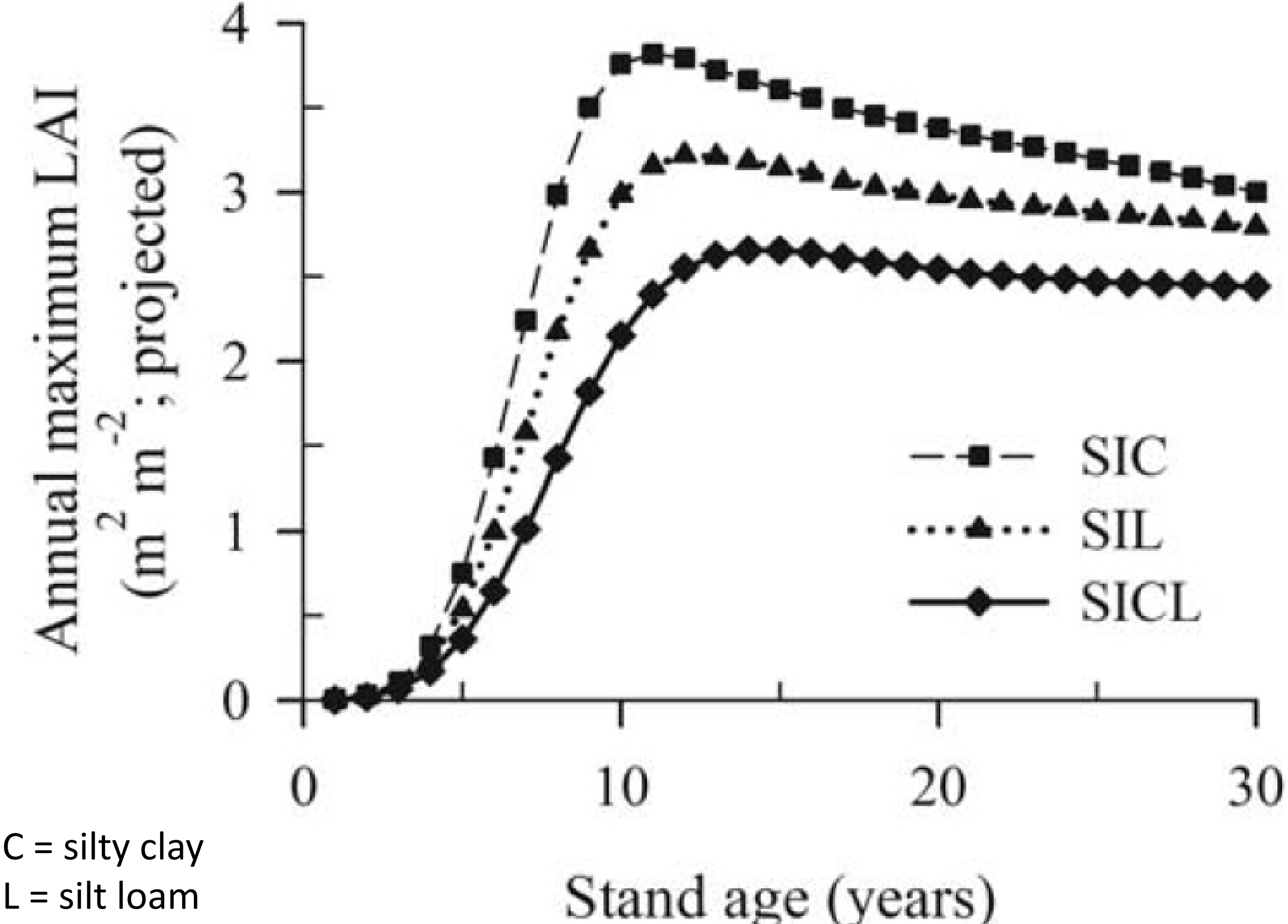


Image year 2008
after all MRR stands were released

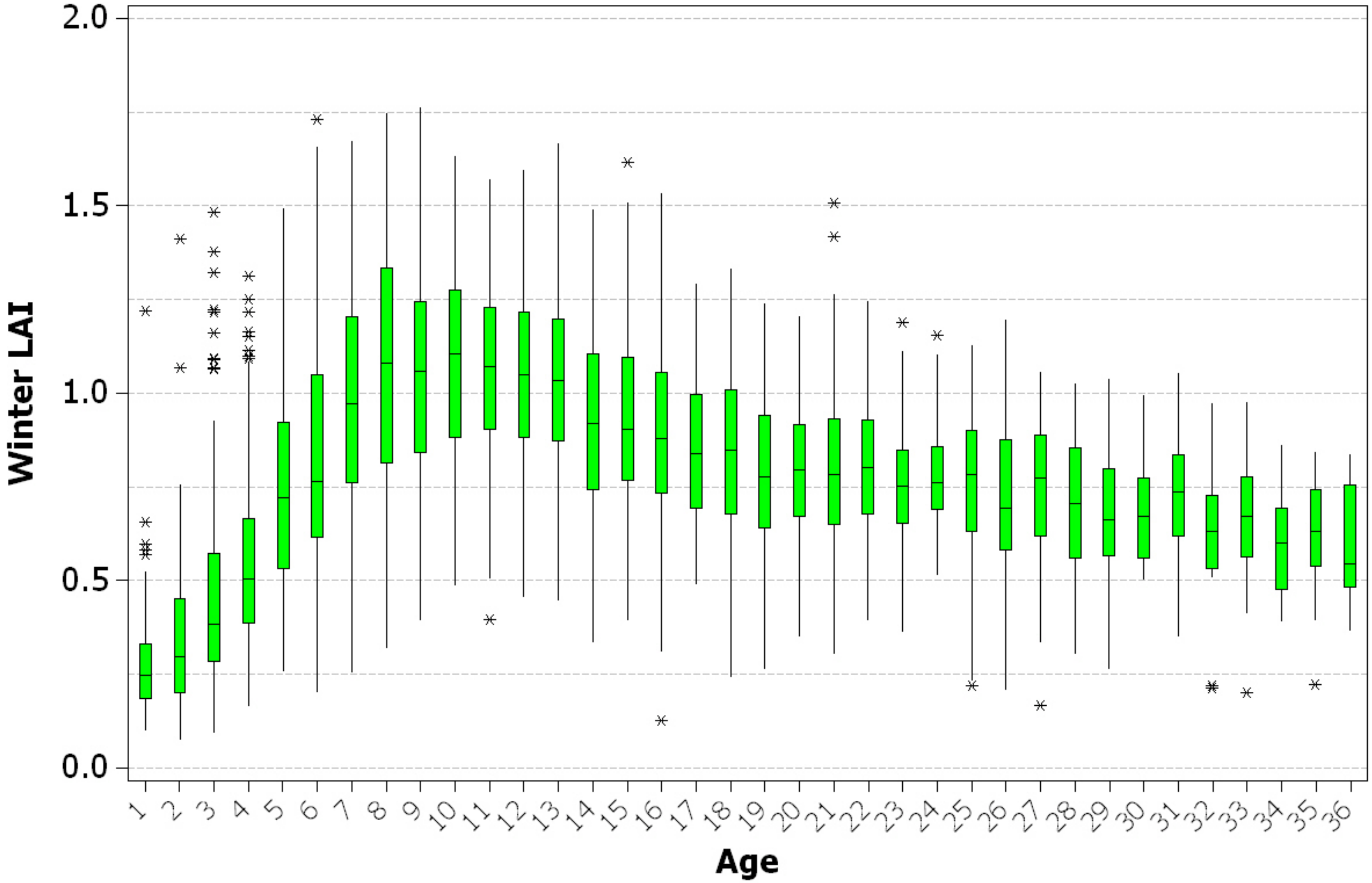
Simulated LAI by Soil Fertility



SIC = silty clay
SIL = silt loam
SICL = silty clay loam

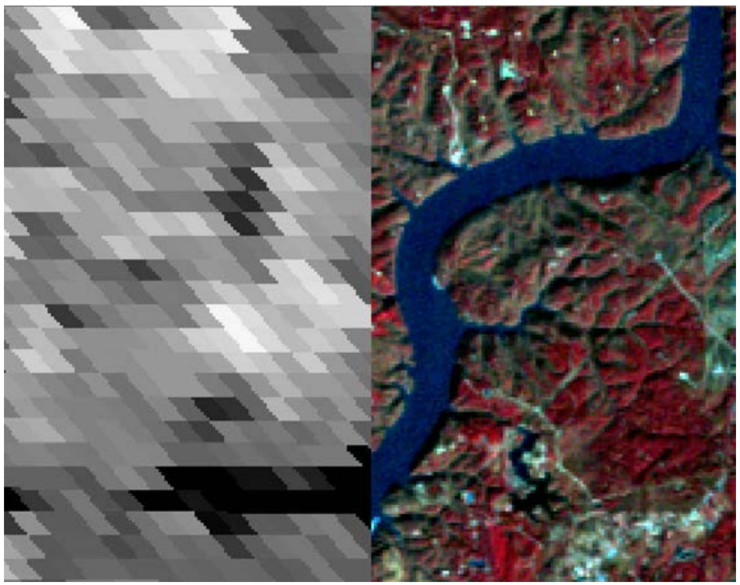
SECRETS 3PG, process model, LAI estimates from Sampson et al. 2008

LAI versus Age

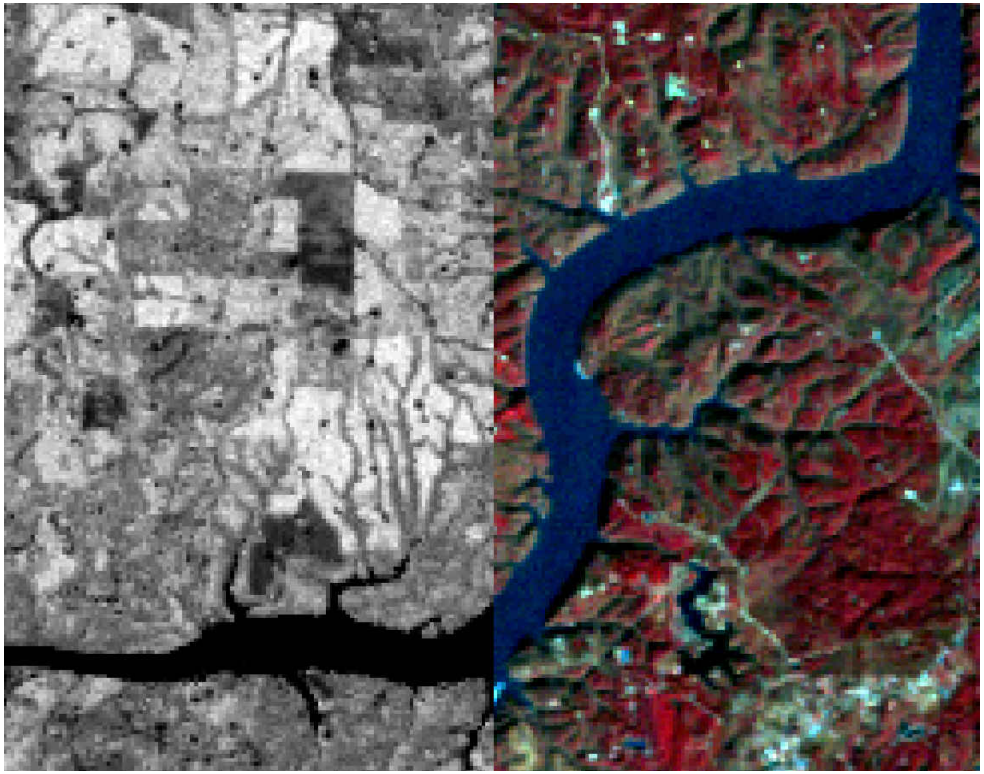


LAI is based on Flores et al. 2006 equation which uses TOA reflectance

STARFM Input/Output

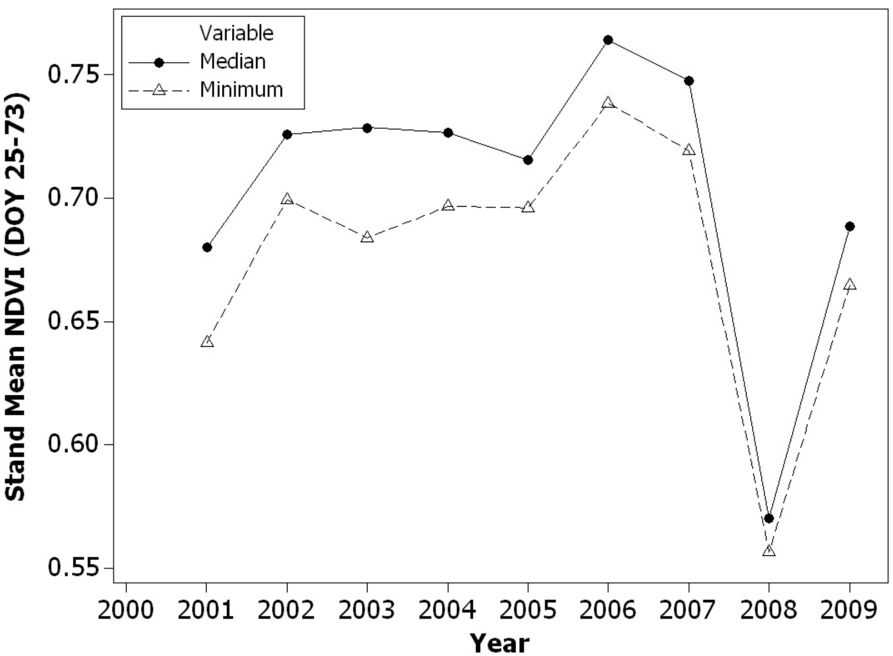


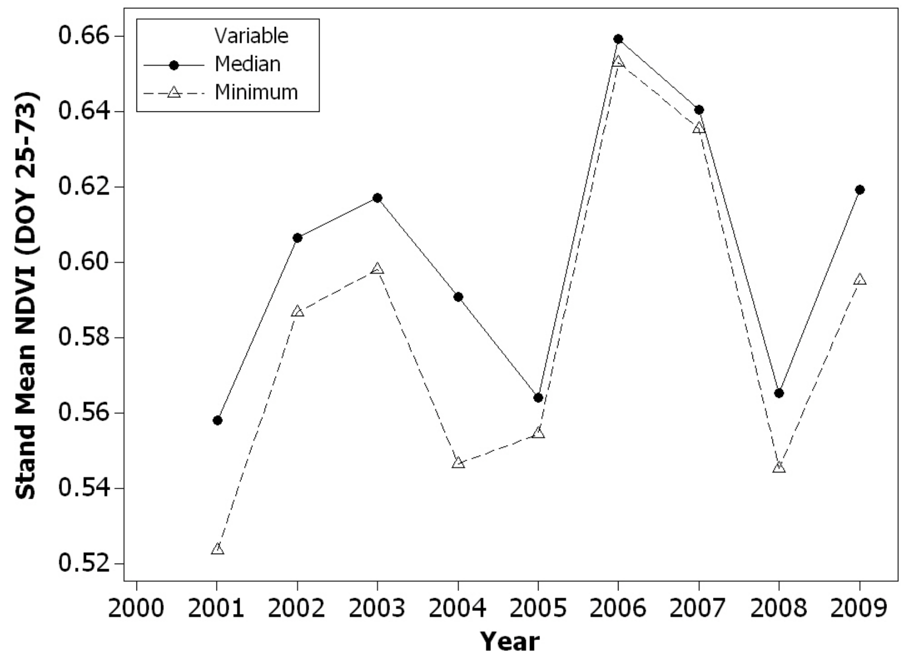
NDVI from MODIS Input
versus
Landsat TM Input



NDVI from STARFM Output
versus Landsat TM Input

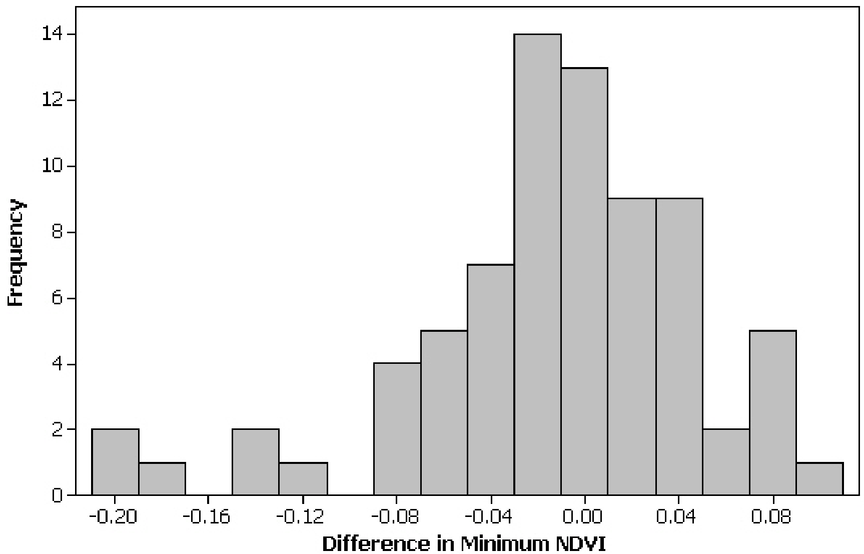
Example NDVI Time Series



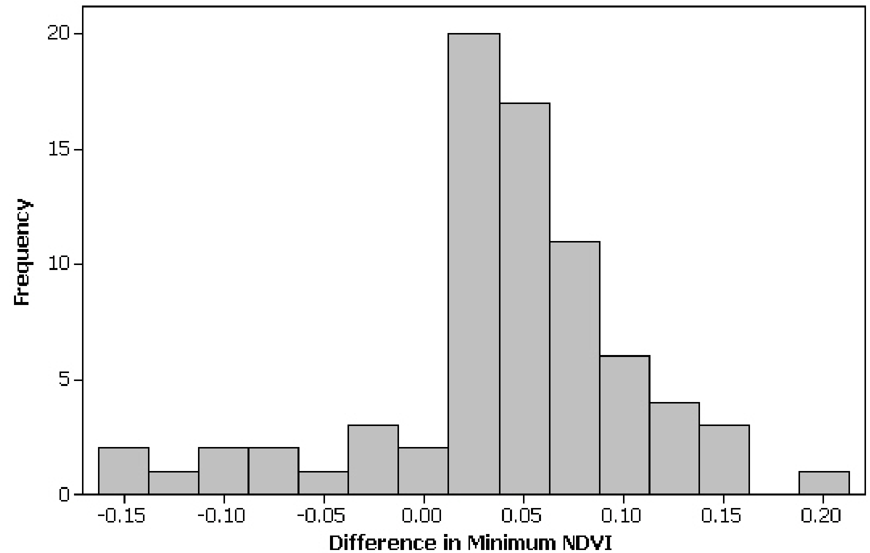


Both stands were planted in 1993, fertilized in 3/2005, and thinned in 8/2007.

NDVI Year to Year Change and Fertilization



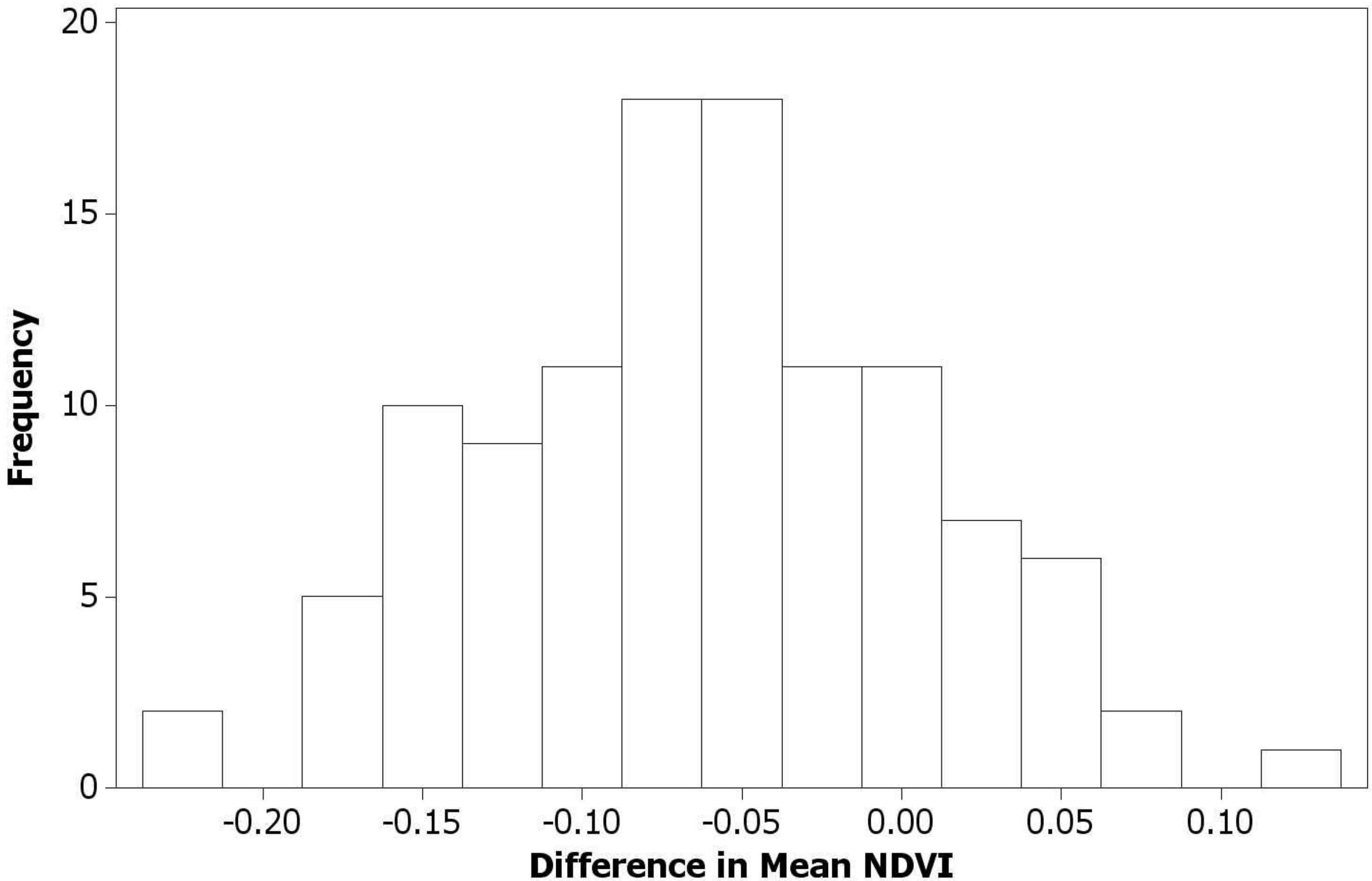
NDVI Year of Fertilization minus NDVI Year before Fertilization



NDVI Year After Fertilization minus NDVI Year of Fertilization

Loblolly pine stands that were established between 1981 and 1996 and that did not receive any other silvicultural treatments within a year of the image dates. Age at fertilization was between 9 and 24.

Thinning Effect on NDVI



111 Stands

Thinned Yr Mean Difference: -0.06

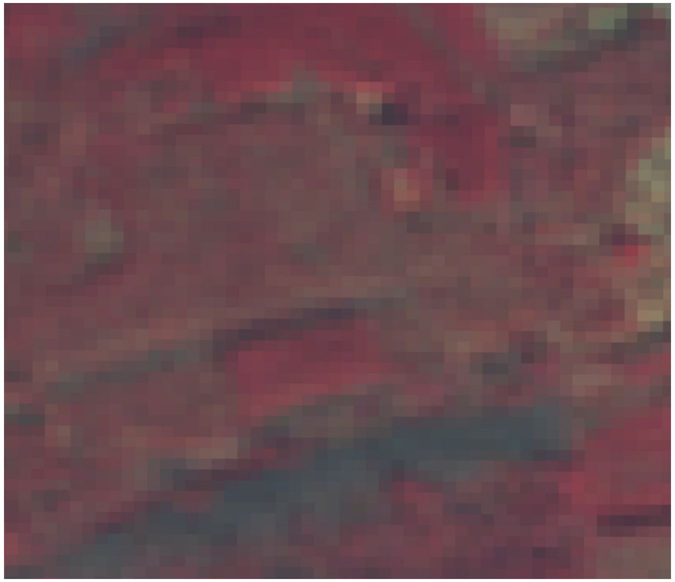
Unthinned Yrs Mean Difference: 0.0025

NDVI year before thinning minus NDVI year after thinning

Spatial Resolution

NAIP
1m

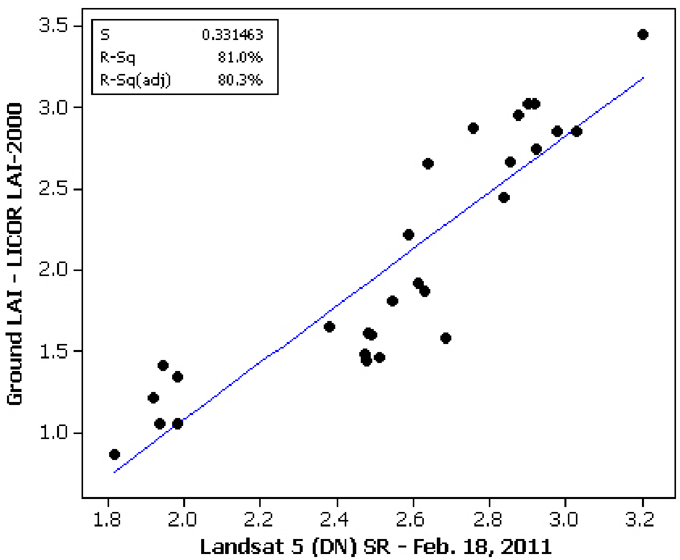
SPOT 5
10m

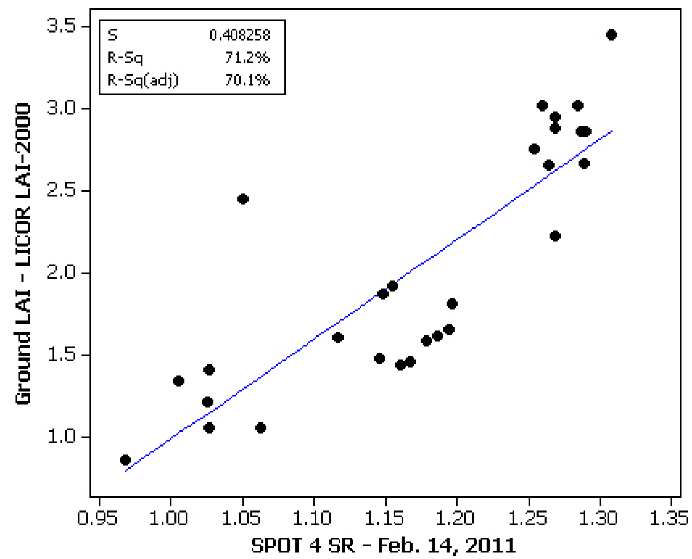


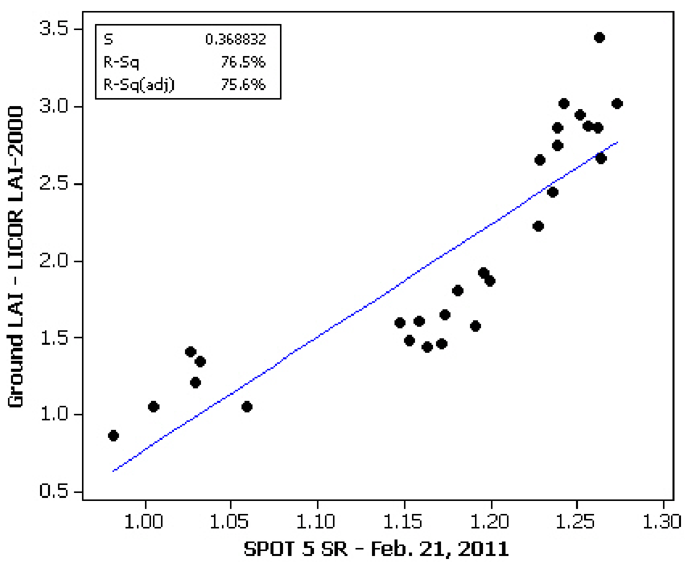
SPOT 4
20m

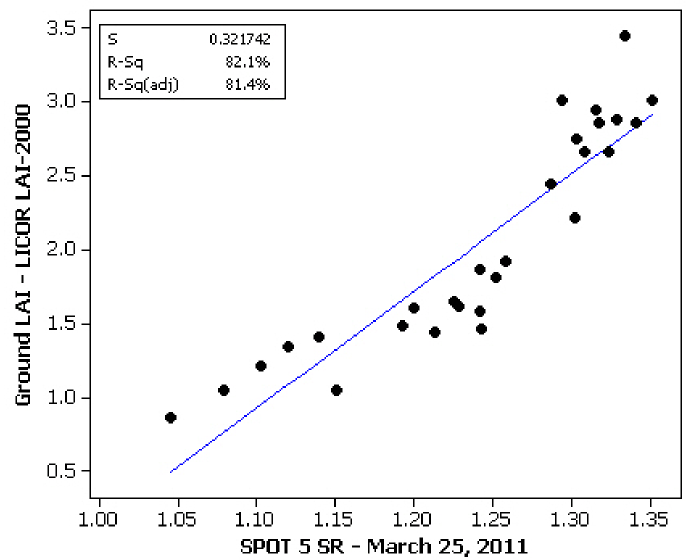
Landsat 5
30m

LAI and Spatial Resolution





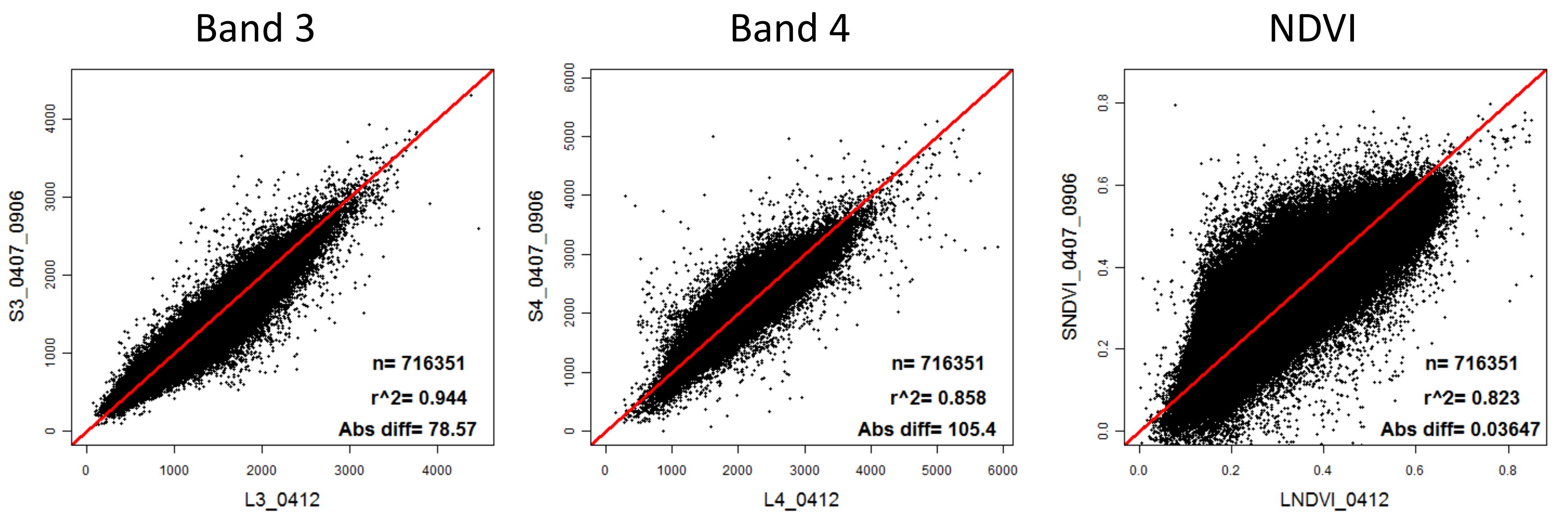




Verification of STARFM applicability to dryland forest environment

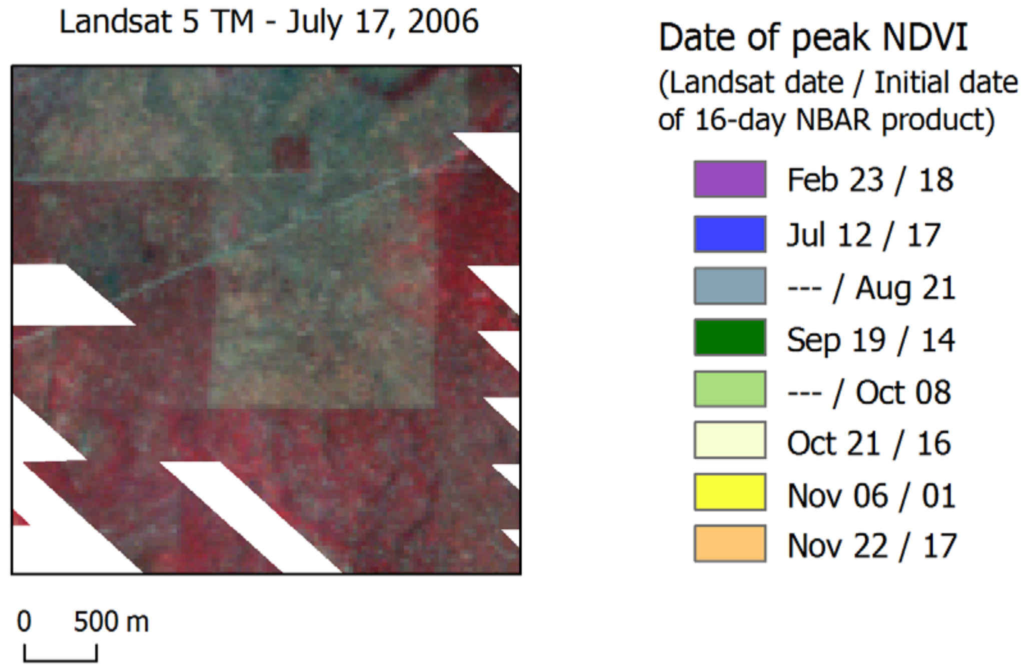
- STARFM base pairs: 500m NBAR MODIS data, Landsat 5 TM; Sep 19, 2006
- STARFM prediction: 14 MODIS dates between Feb and Nov, 2006
- Verification method: Comparison of STARFM images with coincident Landsat images via randomly sampled pixels (5%)

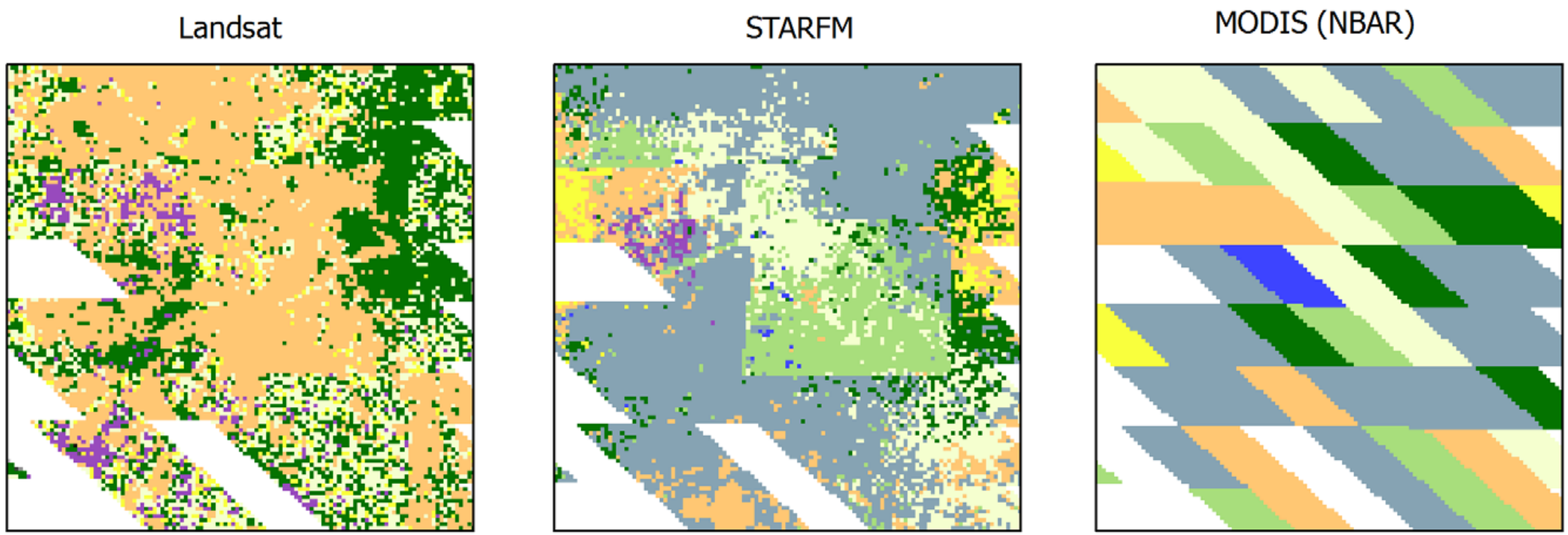
Results: High degree of correlation; i.e., Landsat date Apr 12:



Walker, J.J., de Beurs, K.M., Wynne, R.H., & Gao, F. 2011. An evaluation of data fusion products for the analysis of dryland forest phenology. *Remote Sensing of Environment*, in review.

Figure 3. Corresponding subsets showing the date of peak NDVI retrieved from the Feb - Nov 2006 MODIS (NBAR), Landsat 5 TM, and STARFM time series, as well as the false-color Landsat subset from July 17, 2006. All pixels shown were classified as ponderosa pine in SWReGAP. Visible on the Landsat image is a logged area amid standing forest. Two of the most common peak NDVI dates in the MODIS and STARFM series--August 21 and October 8---are not represented by imagery in the Landsat time series due to cloud cover.





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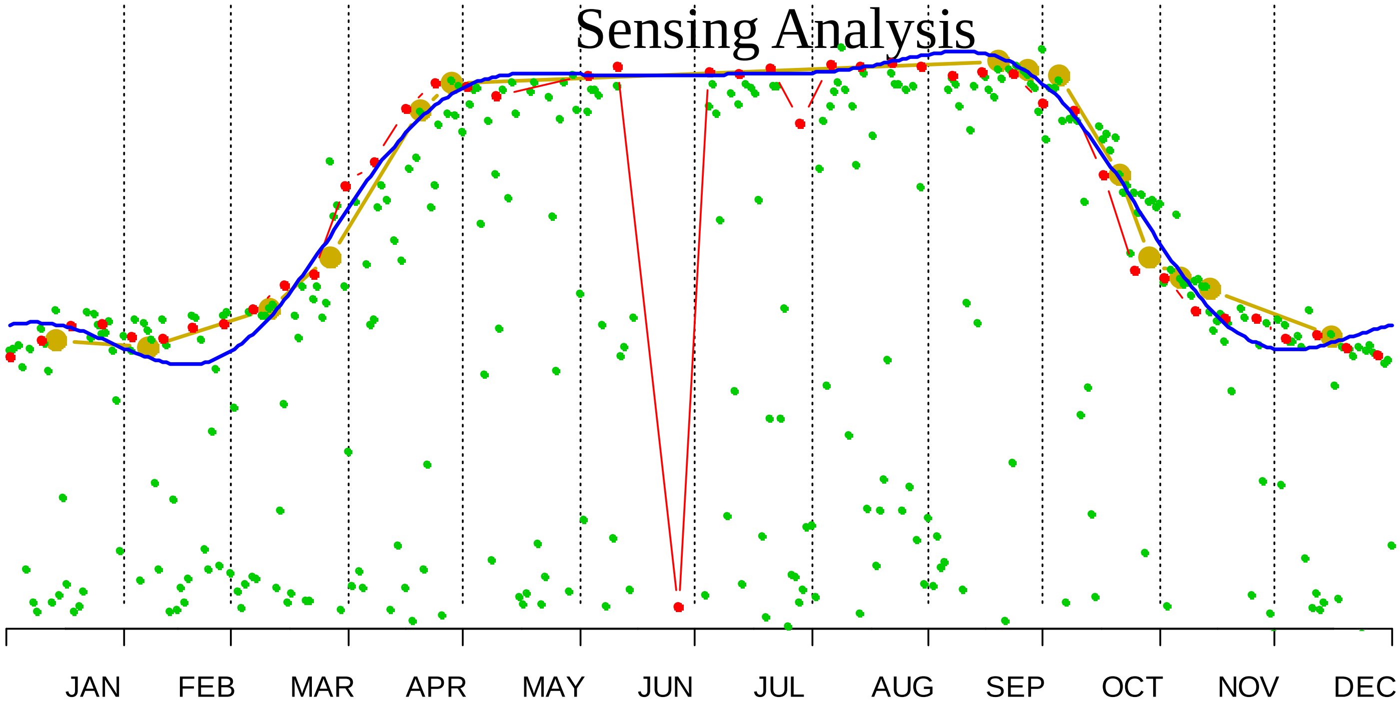
Fitting the Multitemporal Curve

A Fourier Series Approach to the Missing Data Problem in Remote Sensing Analysis



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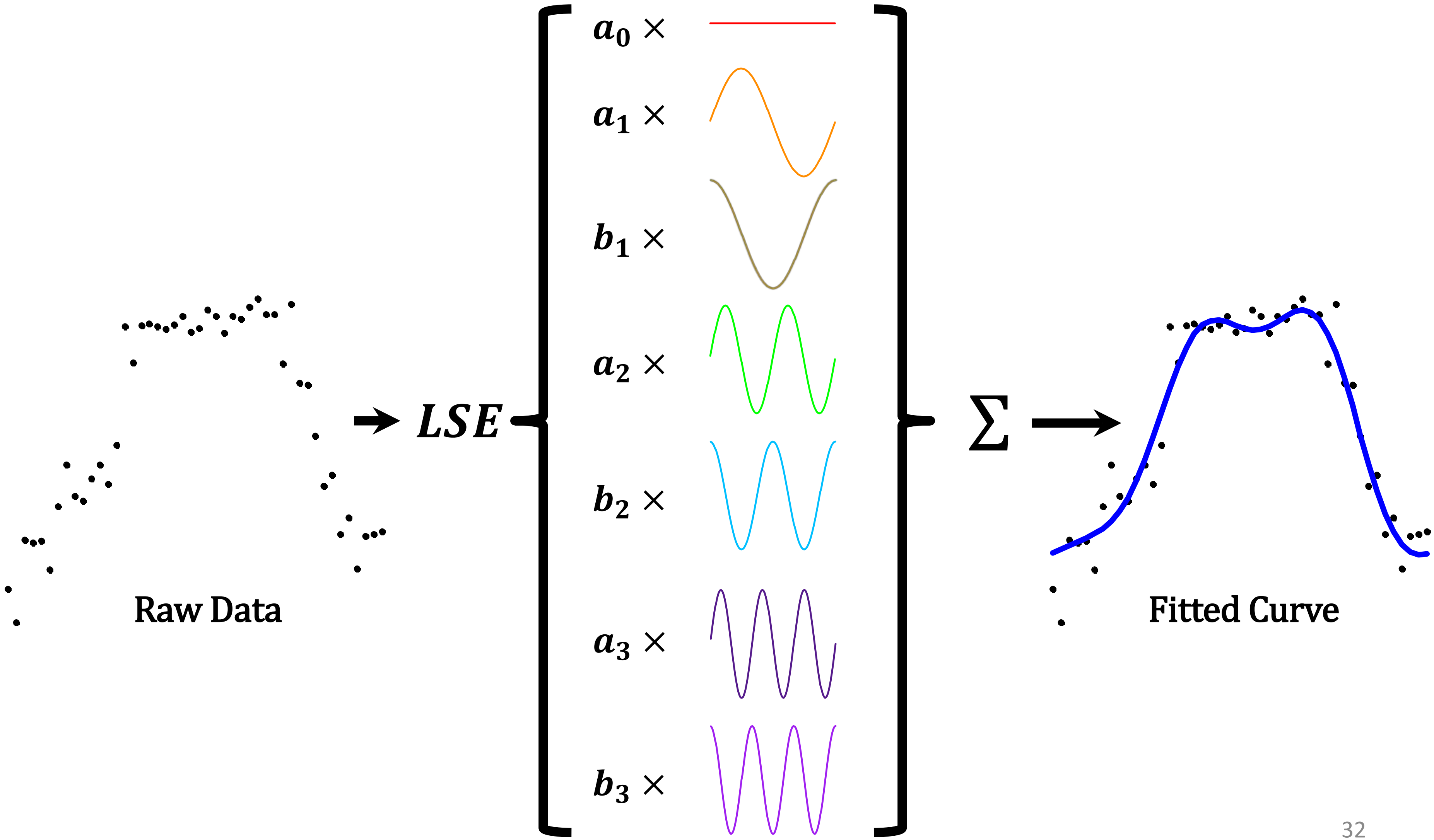
Forest Resources & Environmental Conservation

VirginiaTech

Fourier Regression Algorithm



Advantages of Fourier Regression

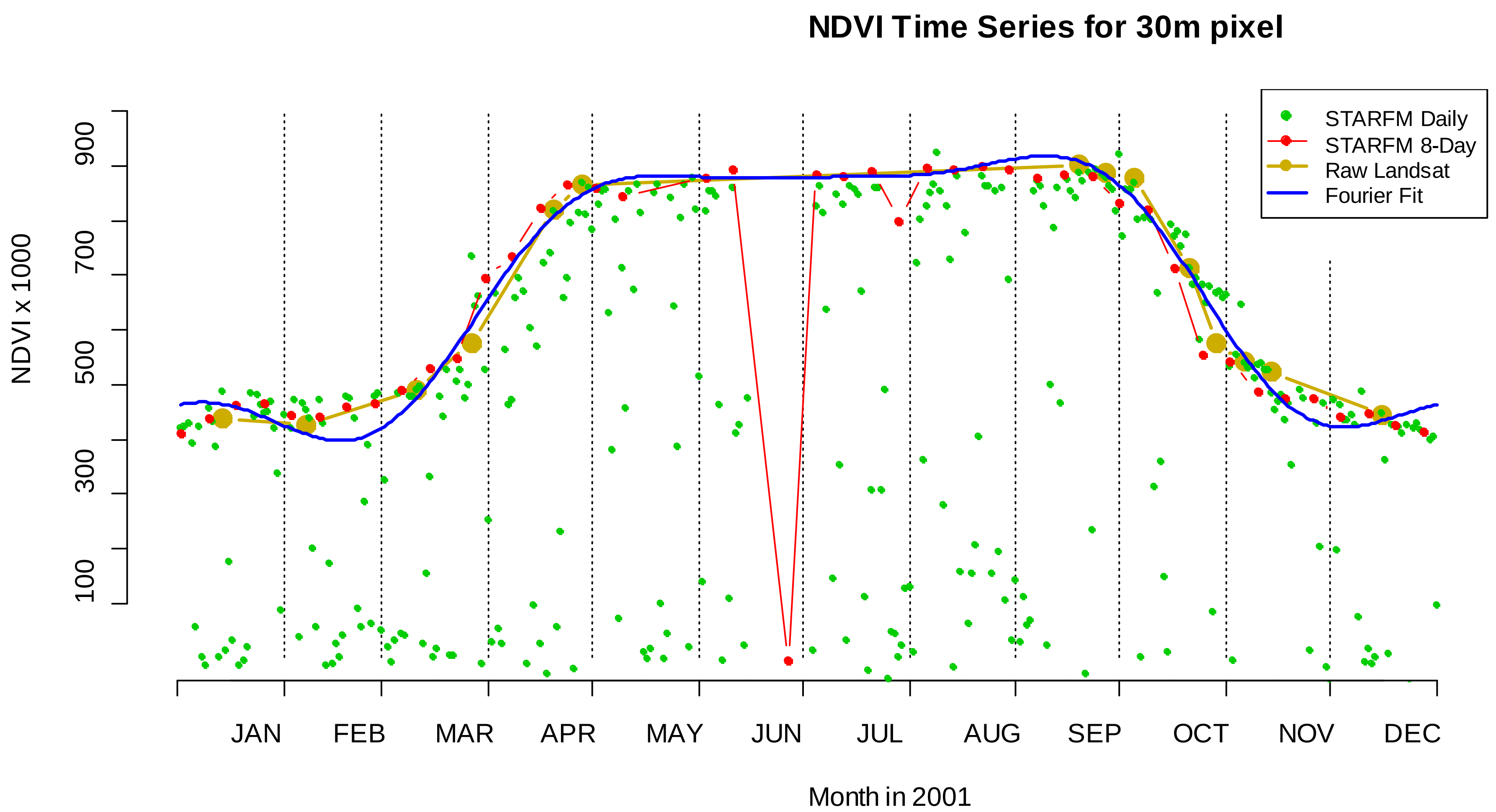
- No ancillary data required
  - Reducing possible error sources
- Fourier terms are orthogonal
  - Reduced multicollinearity
- Fourier series are smooth
  - Facilitates calculus-based approaches to time series analysis
- Can store the Fourier coefficients in raster form instead of generating images for each day of the year
  - Saves space

Data

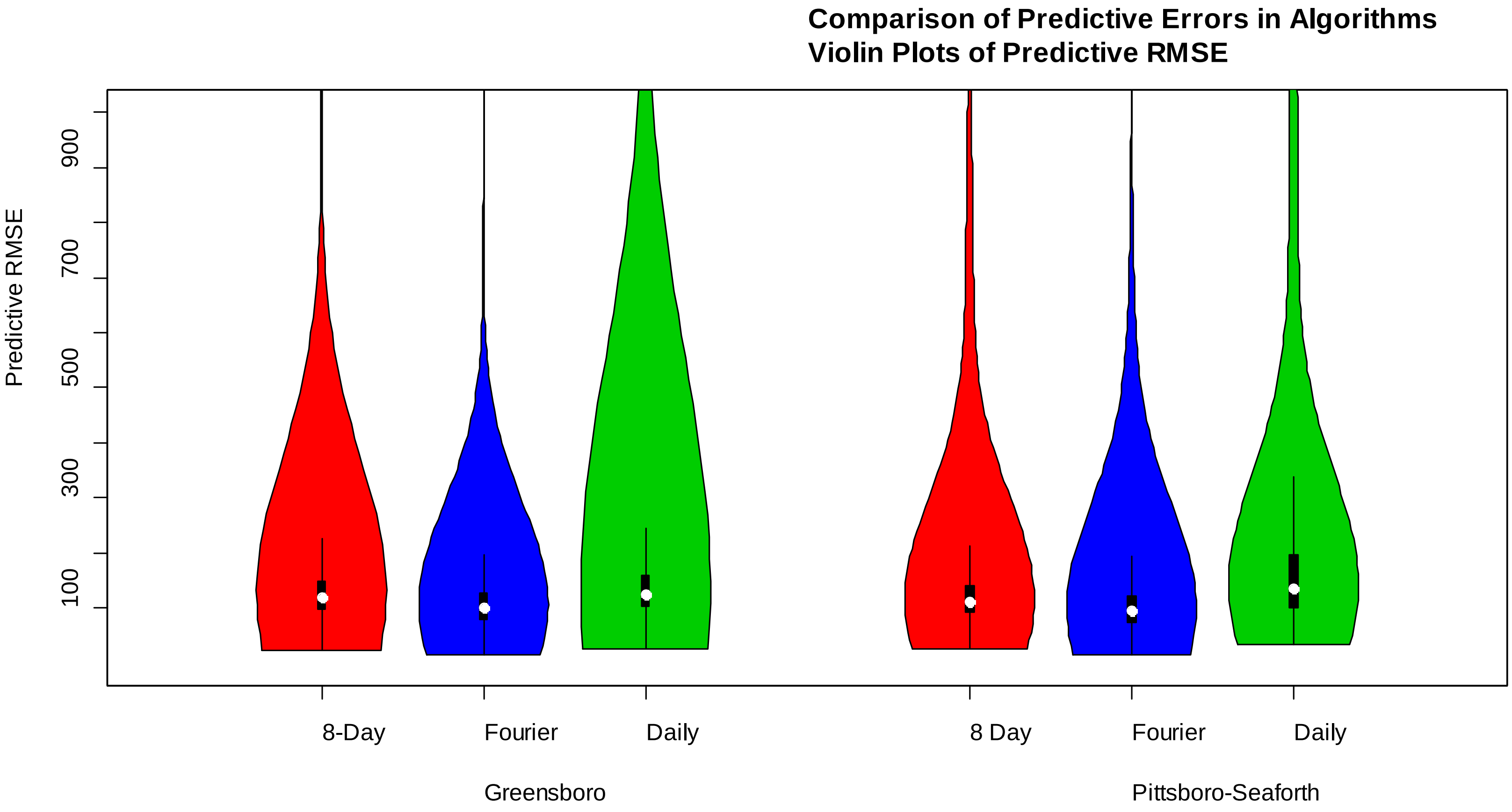
- Study areas
  - Relative proximity intended to control geographical and meteorological factors

Greensboro, NC

Pittsboro-Seaforth, NC


NDVI Time Series for 30m pixel
NDVI x 1000
100
300
500
700
900
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month in 2001
STARFM Daily
STARFM 8-Day
Raw Landsat
Fourier Fit

Results


Comparison of Predictive Errors in Algorithms
Violin Plots of Predictive RMSE
Predictive RMSE
100
300
500
700
900
8-Day
Fourier
Daily
8 Day
Fourier
Daily
Greensboro
Pittsboro-Seaforth

Results

Algorithms with Maximum Predicted R^2 by Pixel
Pittsboro Area

	8-Day STARFM	Fourier Regression	Daily STARFM
Open Water	8%	89%	2%
Developed, Open Space	16%	76%	8%
Deciduous Forest	32%	57%	11%
Evergreen Forest	9%	76%	14%
Mixed Forest	20%	64%	16%
Grassland/Herbaceous	13%	79%	8%
Pasture Hay	9%	85%	6%
Other (<5% of Pixels)	22%	71%	8%
All Classes	***22%***	***68%***	***11%***

Conclusions

	Fourier Regression	STARFM
Advantages	• Robust, accurate prediction and fit • Reduced storage space • No ancillary data • Suited for inter-annual studies • More harmonics = finer fit	• Robust, accurate prediction on cloud-free days • Availability of composite imagery • Able to handle sudden changes on a daily basis • Suited for intra-annual studies, especially for short duration
Disadvantages	• Must have input data at key points of curve • Harmonics limited by quantity of data • Requires at least one year of data • Produces undesirable “wiggles” • Fits poorly when pixel undergoes disturbance	• Nontrivial processing/computing requirements • Susceptible to cloudcover issues • Reduced accuracy in heterogenous areas • MODIS has no blue band, only a blue-green

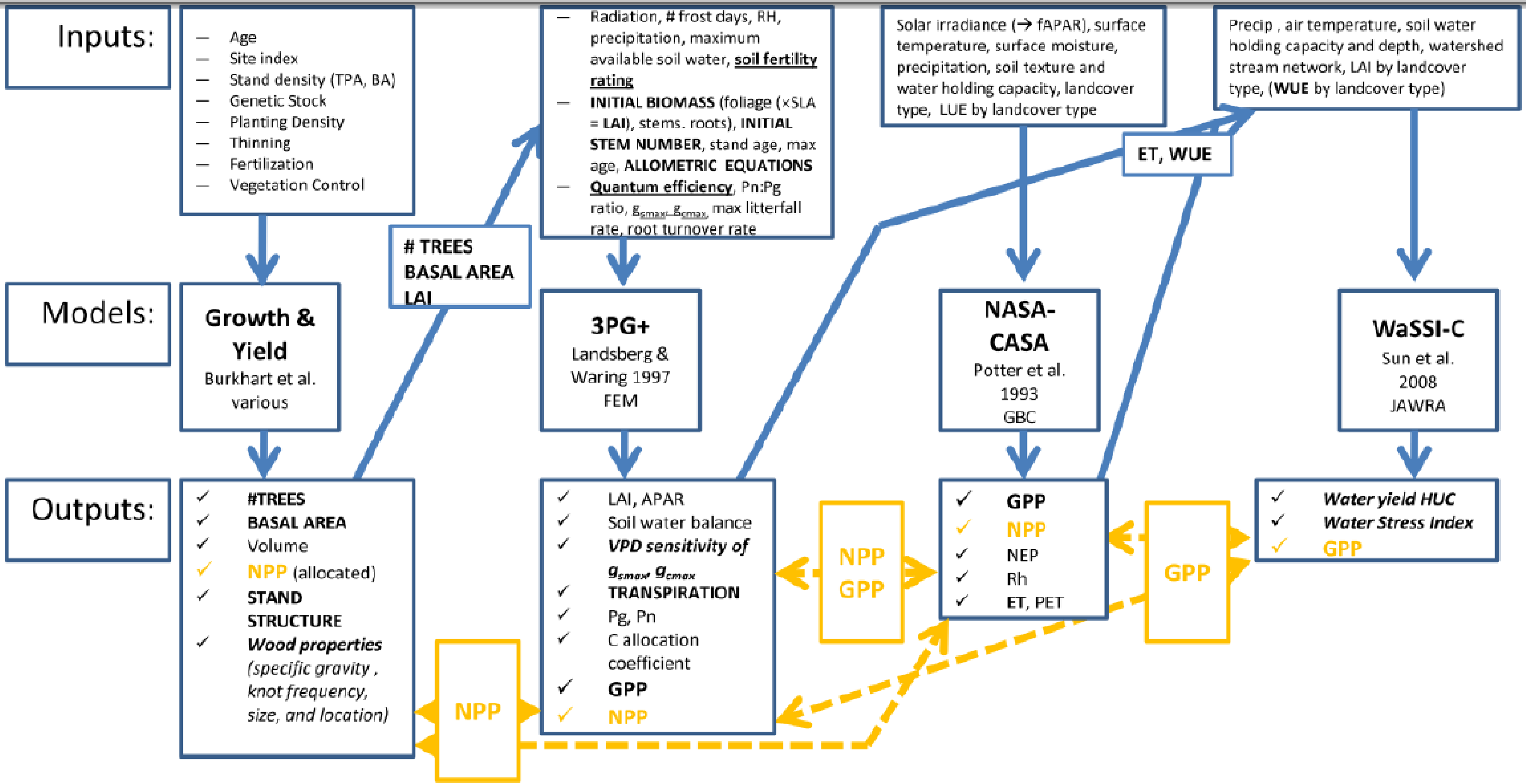


Figure 6. Schematic depiction of the inputs, outputs, and interactions among the four primary models. Solid blue arrows indicate data flow between models, yellow dashed arrows and variable names indicate cross comparison of common model outputs, **BOLD CAPS** input & output parameters indicate variables transferred among models, underlining indicates key sources of stand-level variability, and *italics* indicates terminal outputs unique in scale.

Reflections

- Managed ecosystems are the norm and Landsat has become essential to their management for production of both commodities and ecosystem services
- Facilitating multitemporal analysis is clearly a first order objective of the program
  - Surface reflectance
  - “cloud” sourcing?
  - LAI/fPAR
  - Scenes -> Tile Composites -> Multitemporal “BIP”?
- Professional highlight…